Higher Engineering Science

Analogue Electronics, MOSFETS & Operational Amplifiers

Name: ______________________

Teacher: ___________________

Class: ______________________

Mrs Gault

Learning Intentions

- Designing Voltage Divider circuits to meet a given specification
- Use bipolar transistors as current amplifiers in a circuit
- Use bipolar transistors to create a Darlington Pair or in a push/pull follower formation
- Use N-channel MOSFETs as voltage switching devices
- Perform calculations using different types of Operational Amplifier configurations
- Able to select Operational Amplifiers for a given purpose

Success Criteria

- I can design and construct circuits using sensor inputs and BJT drivers
- I can design and construct circuits using sensor inputs and MOSFET drivers
- I can design and construct Operational Amplifier circuits
- I can test and evaluate analogue electronic solutions against a specification

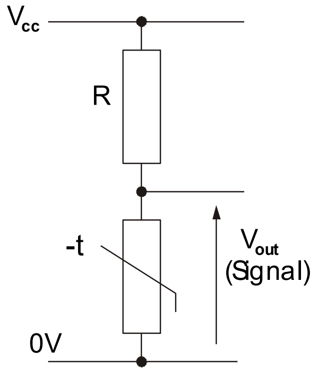
In this unit we will build on the skills learned in National 5 Engineering Science.

Voltage Dividers

Any electronic system can be broken down into three distinct parts.

INPUT transducers convert a change in physical conditions e.g. temperature into a change in an electrical property e.g. voltage.
It can then be processed electronically to produce either a direct measurement of the physical condition, temperature in °C, or to allow something to happen at a set level e.g. switching on the central heating at 20 °C.

Changes in the resistance of an input transducer must be converted to changes in voltage before the signal can be processed. This is normally done by using a voltage divider circuit.



Voltage divider circuits work on the basic electrical principle that if two resistors are connected in series across a supply, the voltage load across each of the resistors will be proportional to the value of the resistors.

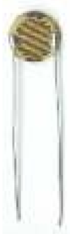
To calculate the voltage over any resistor in a series circuit, we can use Ohm's Law twice or the equation:

$$Voltage = \frac{R}{R_{total}} \times V_{CC}$$

When monitoring physical conditions, one of the resistors in the circuit is an input transducer, the resistance of which will change depending on the physical conditions.

Common Input Transducers

The main sensors that we use in Higher Engineering Science are below. Complete the table to show their symbol, a description of how they operate and an example of where they might be used in real life.

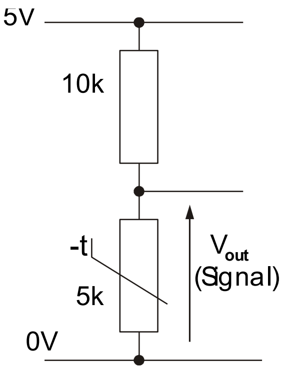
Type	Image	Symbol	Description	Example of how or where it could be used
Thermistor				
Light Dependant Resistor (LDR)				
Variable Resistor				

Voltage Divider Calculations

Assignment 1.01

Calculate the signal voltages produced by the following voltage divider circuits:

a)



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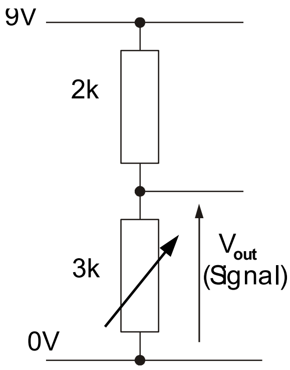
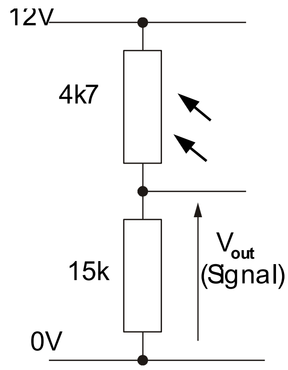
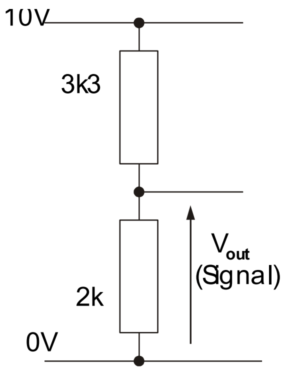


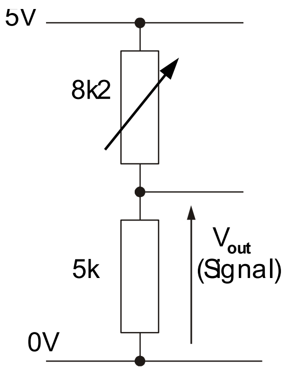
c)



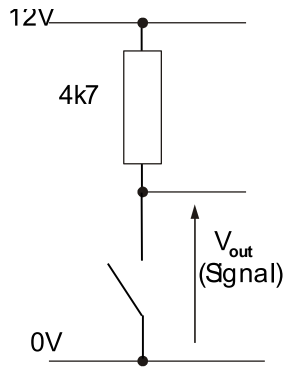
d)



e)

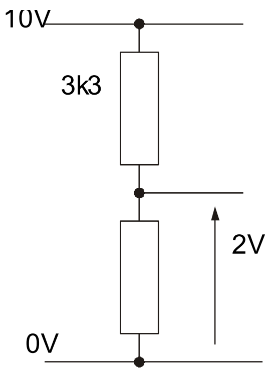


f)

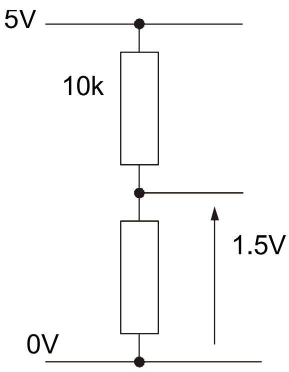


Calculate the size of the unknown resistor required for the given output voltages:

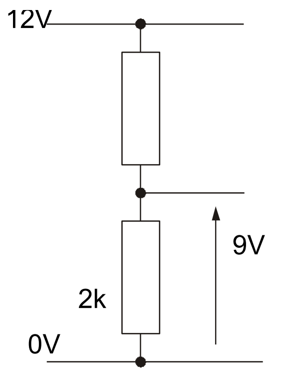
g)



h)



i)

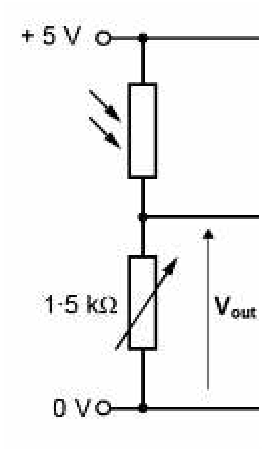


Voltage Divider Descriptions

Assignment 1.02

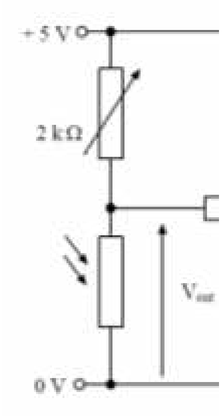
Write a description about how each of the circuits below operate.

a)

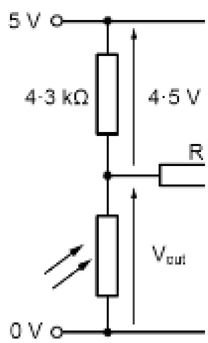


As the light level increases the LDR's resistance decreases.
As the light level increases V_{out} increases.
The variable resistor acts as a sensitivity control

b)



c)



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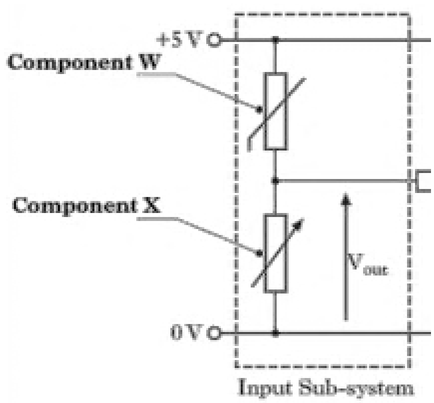
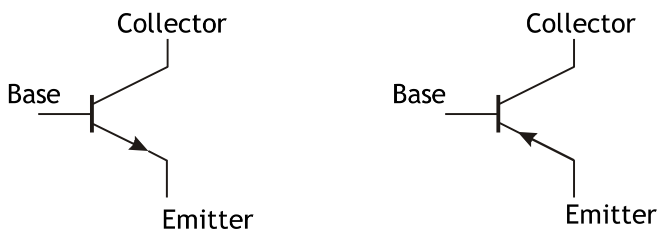


Amplification

Input transducers that produce voltage, rarely produce sufficient voltage for most applications. Their outputs have to be amplified.

Amplifying devices are said to be active components, as opposed to non-amplifying components (resistors, capacitors etc.) which are known as passive components. The extra energy required to operate the active component comes from an external power source (battery, transformer, etc.).

The most common active device in an electronic system is the bipolar junction transistor (or simply transistor for short). Two types are available, pnp or npn.



npn Type   pnp Type

The transistor has to be connected into circuits correctly. The arrow head on the emitter indicates the direction of "conventional" current flow (positive-to-negative).

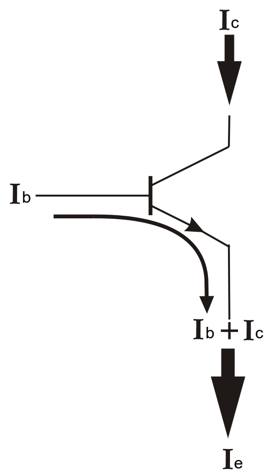
Both types of transistors operate in the same way.

For convenience, only the NPN will be considered.

N**P**N transistors operate when the base is made **P**ositive

PNP transistors operate when the base is made **N**egative

In the common emitter mode, a small current flowing between the base and emitter junction will allow a large current to flow between the collector and emitter.



It can be seen that: $I_e = I_b + I_c$

Since I_b is usually much smaller than I_c, it follows that I_e is approximately = I_c

The bipolar transistor is a current-controlled amplifying device.

The current gain (or amplification) of the transistor is defined as the ratio of collector: base currents

$$current \quad gain = \frac{Collector \quad current}{Base \quad current}$$

$$h_{FE} = \frac{I_c}{I_b}$$

In practice, the maximum allowable currents will depend on the make of transistor used.

Forcing the transistor to carry currents greater than these will cause the transistor to overheat and may damage it.

Assignment 1.03

a) Calculate the gain of a transistor if the collector current is measured to be 10 mA when the base current is 0.25 mA.

b) Calculate the collector current through a transistor if the base current is 0.3 mA and h_{FE} for the transistor is 250.

c) What collector current would be measured in a BC107 transistor if the base current is 0.2 mA and h_{FE} is 100?

Transistor Switching Circuits

In order to generate a current in the base of the transistor, a voltage must be applied between the base - emitter junction (V_{be}).

It is found that no current flows in the base circuit unless V_{be} is above 0.6 Volts.

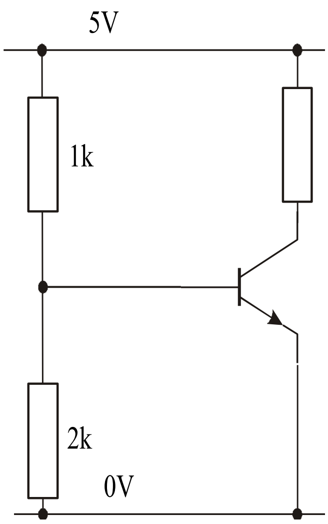
When the base - emitter voltage reaches about 0.7 V, the resistance between the base emitter junction starts to change such that the base - emitter voltage remains at about 0.7 V. At this point the transistor is said to be **saturated**. Increasing the base current further has no effect on the collector current. The transistor is fully ON.

It can be assumed that if the transistor is turned ON, V_{be} = 0.7 V

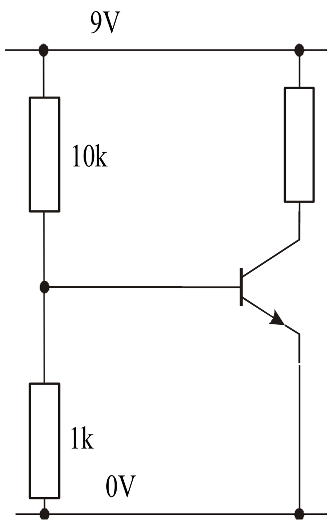
Assignment 1.04

For each of the circuits shown, calculate V_{be} and state if the transistor is ON or OFF.

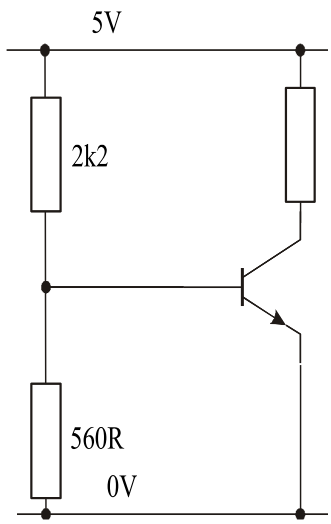
a)



b)

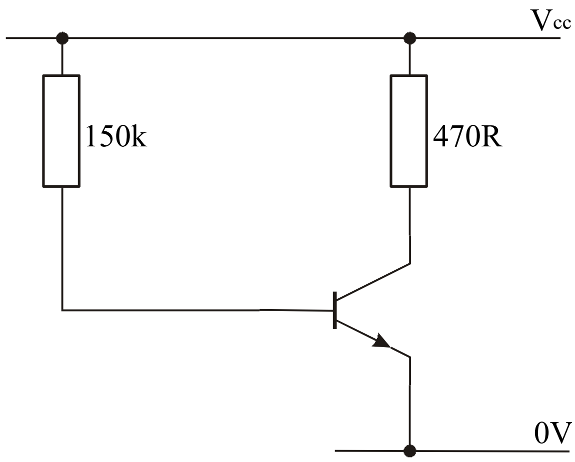


c)



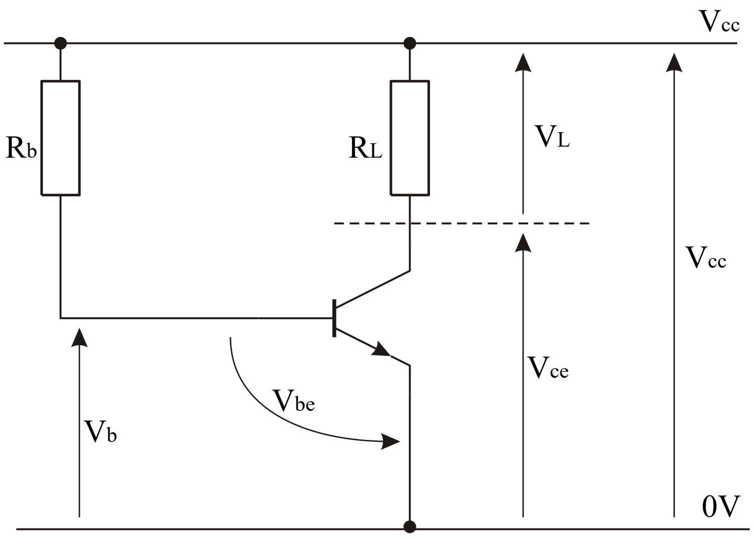
Worked Example

Consider the circuit shown below.



If the transistor is ON, calculate the collector current and V_{ce} , if h_{FE} =200 and V_{CC} = 9 Volts

The circuit below shows currents and voltages using standard notation.



Step 1

The voltage between the base and emitter junction is always about 0.7 V
Since the emitter is connected to the ground line (0V), V_b= 0.7 V

Step 2

The voltage dropped over the base resistor can then be calculated
Voltage drop = V_{CC} - V_b = 9 - 0.7 = 8.3 Volts

Step 3

The base current is calculated using Ohm's law

$$I_b = \frac{V_{dropped}}{R_b} = \frac{8.3}{150k} = 0.00553mA$$

Step 4

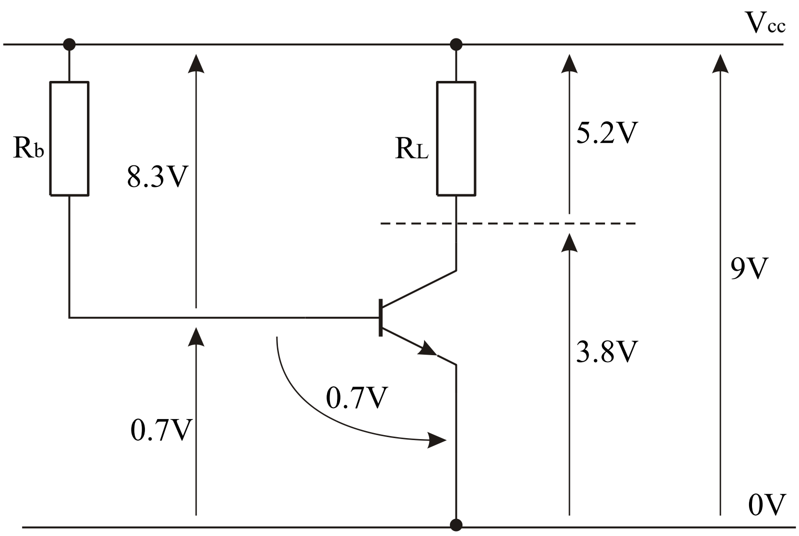
I_c is calculated knowing h_{FE}
I_c = h_{FE} x I_b = 200 x 0.0553 = <u>11.06 mA</u>

Step 5

V_L is calculated using Ohm's law
V_L = I_c x R_L = 11.06 mA x 470 = 5.2 V

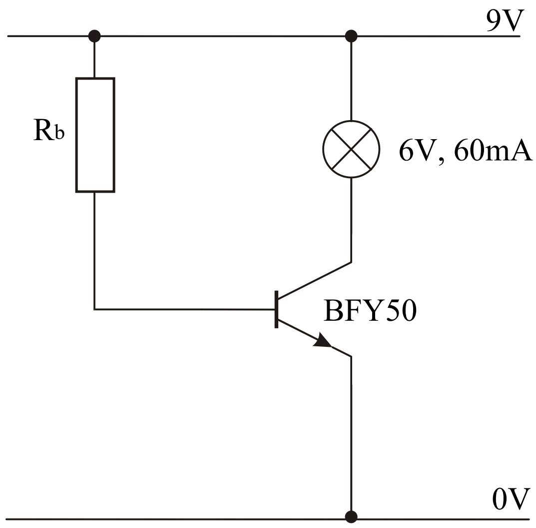
Step 6

V_{ce} is calculated
V_{ce} = V_{cc} - V_L = 9 - 5.17 = 3<u>.8 V</u>



Assignment 1.05

A 6 V, 60 mA bulb is connected to the collector of a BFY50 transistor as shown.

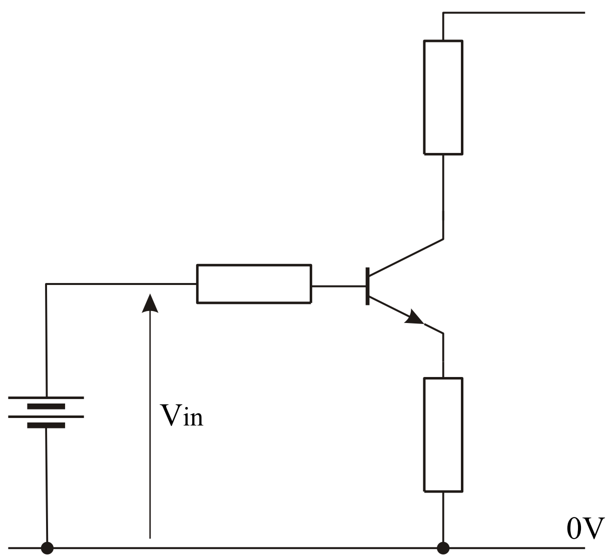


If the gain of the transistor is 30, determine the size of the base resistor R_b required to ensure that the bulb operates at its normal brightness.

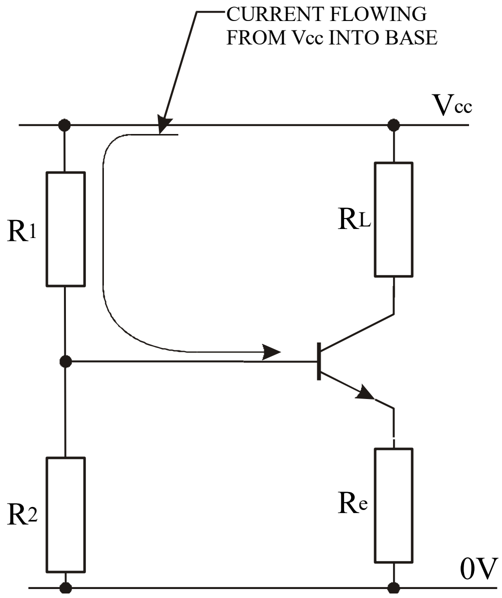
Practical Considerations

Care must be taken to ensure that the maximum base current of the transistor is not exceeded.

When connecting the base of a transistor directly to a source, a base protection resistor should be included. This will limit the maximum current into the base.



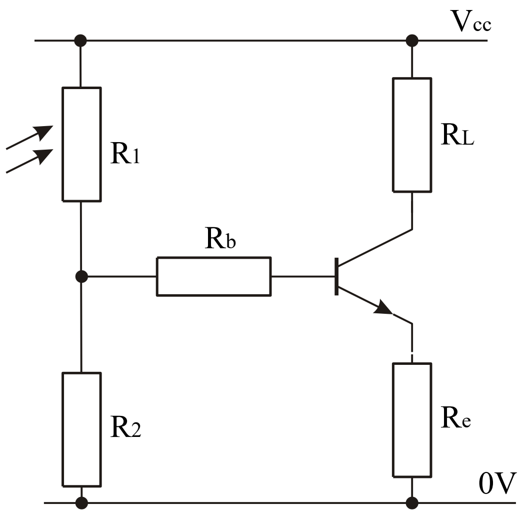
If the transistor is to be connected to a potential divider circuit then the maximum possible current into the base will depend on R_1 (see below).



The maximum possible current through R_1 (and hence into the base) would be

$$= \frac{V_{CC}}{R_1}$$

hence if R_1 is large, the base current will be small and therefore no damage should occur. If R_1 is small (or has the capability of going small e.g. using a variable resistor as R_1), a protection resistor must be included in the base.

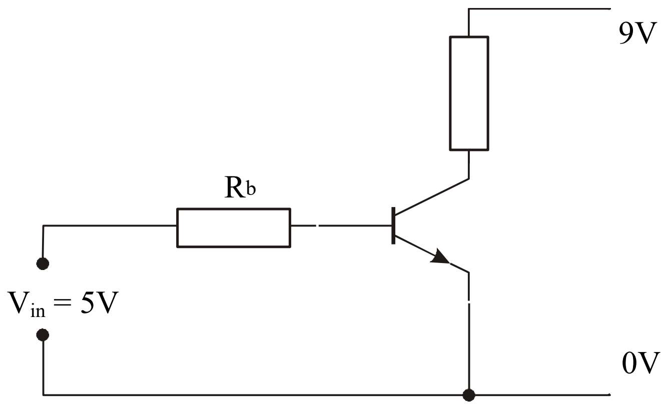


If $R_1 = 0$, the maximum possible current into the base $= \frac{V_{CC}}{R_b}$ hence R_b can be calculated if V_{CC} and the maximum allowable base current is known.

Most data sheets will quote the maximum collector current and h_{FE} and so the maximum allowable base current can be calculated.

Assignment 1.06

Assume $I_{c(max)}$ for the transistor shown below is 100 mA and h_{FE} is 200.



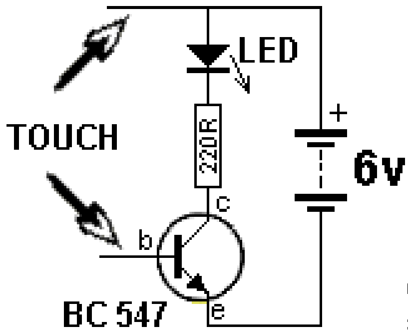
Calculate:

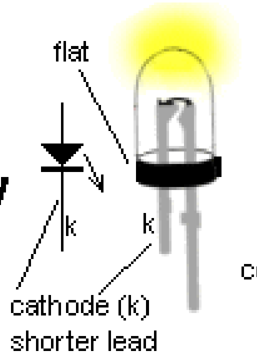
a) the maximum allowable base current.

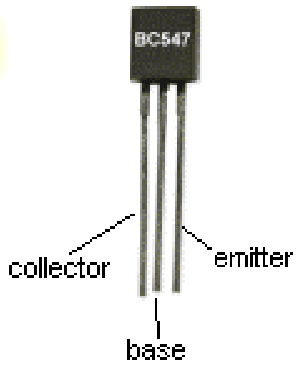
b) the size of protection base resistor required (remembering V_{be} = 0.7V, and R = V/I)

Assignment 7

Connect the LED, 220 ohm resistor and transistor as shown in the photo. Touch the top point with two fingers of one hand and the lower point with fingers of the other hand and squeeze.



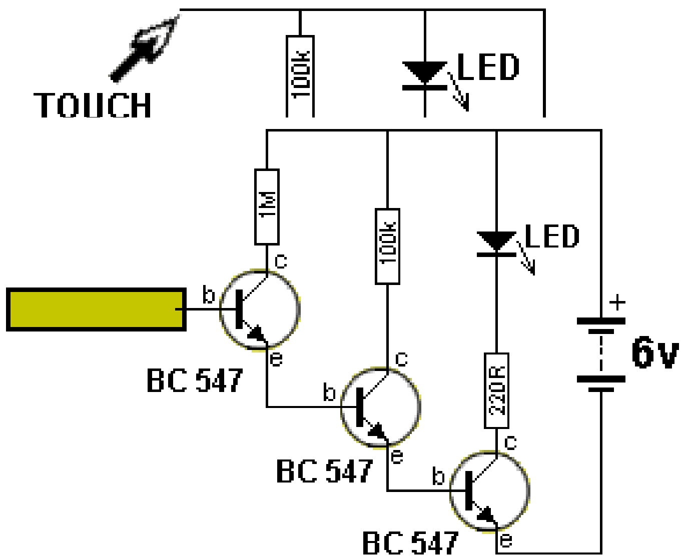




The LED will turn on brighter when you squeeze harder.

Your body has resistance and when a voltage is present, current will flow through your body (fingers). The transistor is amplifying the current through your fingers about 200 times and this is enough to illuminate the LED.

A second transistor has been added in place of your fingers. This transistor has a gain of about 200 and when you touch the points shown on the diagram, the LED will illuminate with the slightest touch. The transistor has amplified the current (through your fingers) about 4000 times.

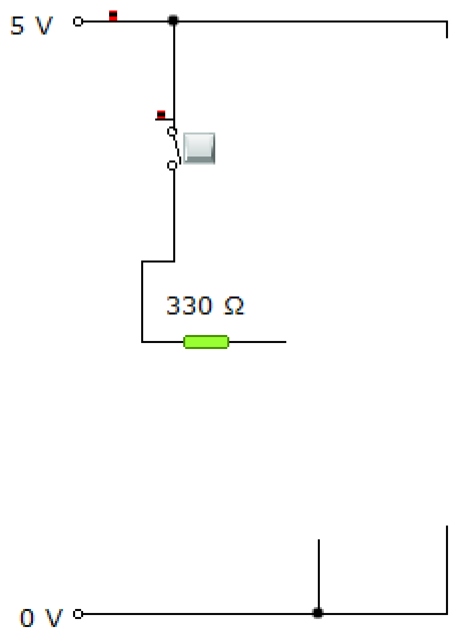


8 MILLION GAIN!

This circuit is so sensitive it will detect "mains hum." Simply move it across any wall and it will detect where the mains cable is located. It has a gain of about 200 x 200 x 200 = 8,000,000 and will also detect static electricity and the presence of your hand without any direct contact. You will be amazed what it detects! There is static electricity EVERYWHERE!

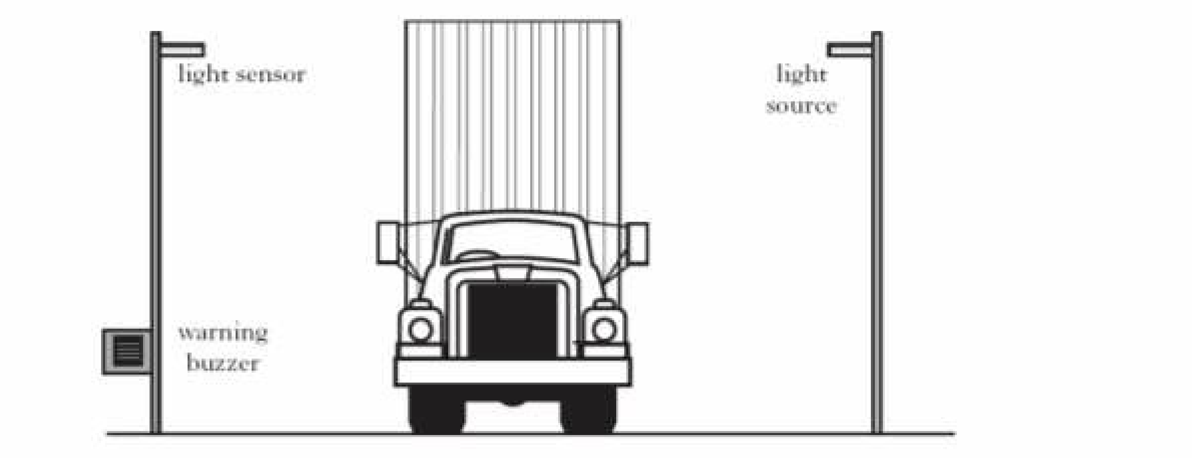
ASSIGNMENT 1.08

Simulate the circuits from Assignment 1.07 using Yenka. The first circuit is started for you.

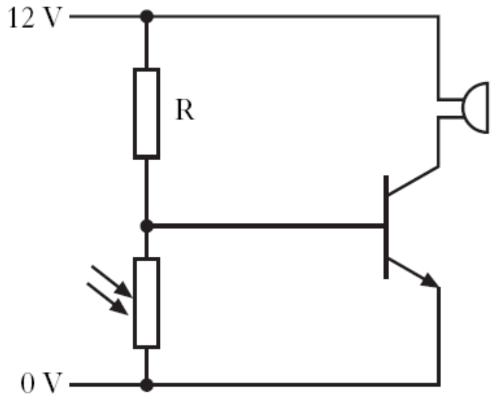


ASSIGNMENT 1.09

A safety system is installed just before the entrance to a warehouse to provide an audible warning to a driver if the vehicle is too high.



The electronic circuit for the safety system is shown below.



At a light level of 200 lux the voltage across the LDR is 0.6 V.

(a) Calculate the value of resister R.

When a vehicle blocks the light beam a base current of 0.8mA flows. The buzzer is rated at 12V, 1W.

(b) Calculate the minimum gain of the transistor necessary to cause saturation when a vehicle blocks the light beam. Assume that the voltage across the buzzer is 12V when the transistor saturates.

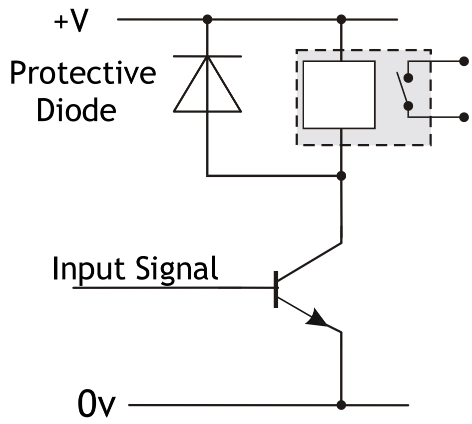
It was found that the sound from the buzzer was not loud enough. It was decided to use a 230V siren instead.

(c) Draw a modified circuit diagram showing how the 230V siren would be controlled. The same buzzer symbol may be used to represent the siren.

DRIVING LARGE LOADS

In some circumstances, the current (or voltage) required to operate an output transducer may be too large for a transistor to handle e.g. for heating elements, heavy motors or for machines operating from the mains supply, etc.

In these circumstances, the transistor circuit can be used to drive a relay. The contacts of the relay are then used in a separate circuit to operate the output transducer.



When the transistor is switched on, current flowing through the collector causes the coil in the relay to become an electromagnet, this pulls the contacts closed and completes the circuit to the motor.

The diode protects the transistor when the relay switches off since large "back" voltages can be produced.

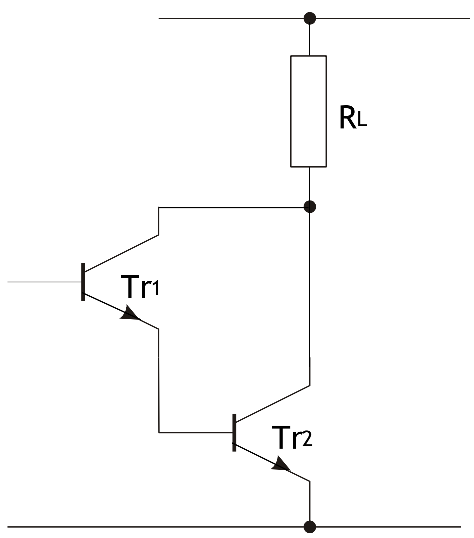
THE DARLINGTON PAIR

In order to obtain higher gains, more than one transistor can be used, the output from each transistor being amplified by the next (known as cascading).

Increasing the gain of the circuit means:

1. the switching action of the circuit is more immediate;
2. a very small base current is required in switching;
3. the input resistance is very high.

A popular way of cascading two transistors is to use a Darlington pair as shown below.

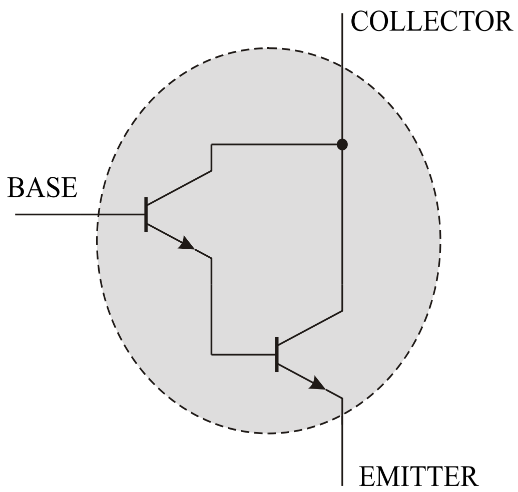


The current gain of the "pair" is equal to the product of the two individual h_{FE}'s.

e.g. if two transistors, each of gain 50 are used, the overall gain of the pair will be 50 x 50 = 2500

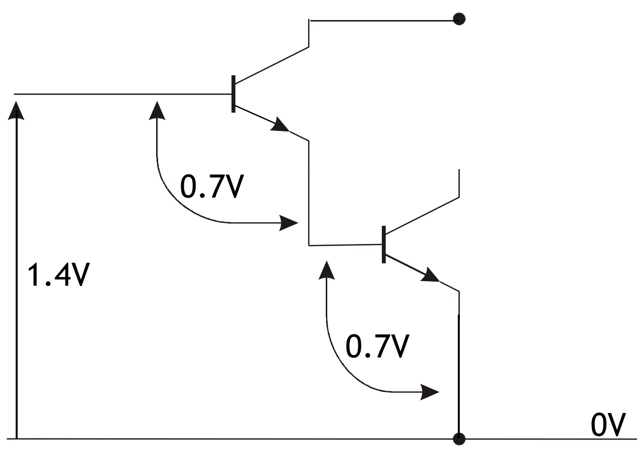
$$A_I = h_{FE1} \times h_{FE2}$$

Because of the popularity of this circuit design, it is possible to buy a single device already containing two transistors.



In a Darlington pair, both transistors have to be switched on since the collector-emitter current of Tr_1 provides the base current for Tr_2.

In order to switch on the pair, each base-emitter voltage would have to be 0.7V.

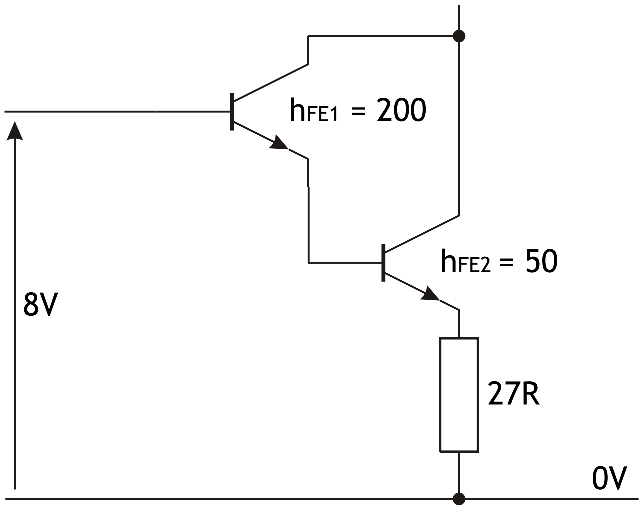


The base-emitter voltage required to switch on the pair would therefore have to be 1.4V.

WORKED EXAMPLE

For the Darlington pair shown below calculate:

a) the gain of the pair;
b) the emitter current;
c) the base current.



Step 1

the overall gain = product of the individual gains

$$A_I = h_{FE1} \times h_{FE2} = 200 \times 50 = 10000$$

Step 2

the voltage over the load resistor must be the input voltage to the base minus the base-emitter voltage required to switch on the pair

$V_L = V_{in} - V_{be} = 8 - 1.4 = 6.6$ V

Step 3

the emitter current in the load resistor can be obtained from Ohm's law

$$I_e = \frac{V_L}{R_L} = \frac{6.6}{27} = 0.244A$$

Step 4

since the gain is very high, $I_c = I_e$

the gain for any transistor circuit = I_c/I_b

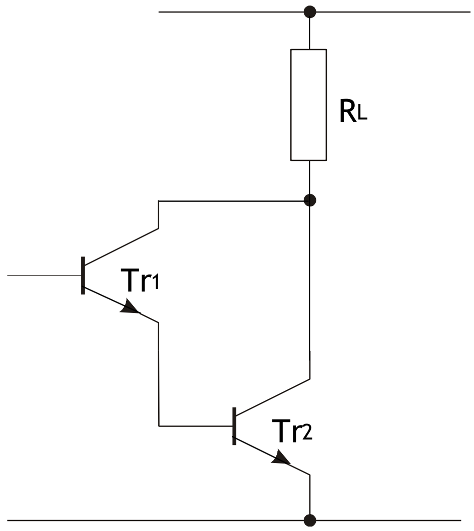
hence knowing I_c and A_I, I_b can be calculated

$$A_i = \frac{I_c}{I_b} \Rightarrow I_b = \frac{I_c}{A_i} = \frac{0.244}{10000} = 24.4 \times 10^{-6} A$$

ASSIGNMENT 1.1

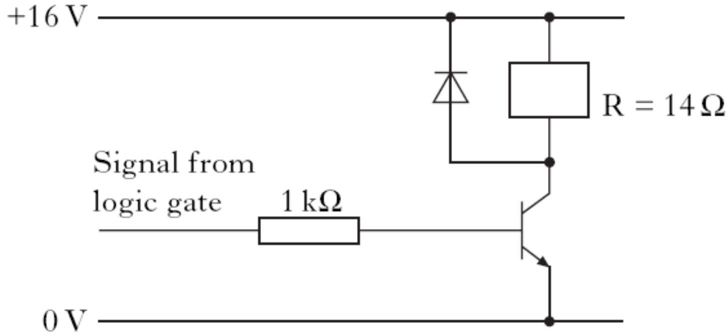
For a Darlington pair circuit the gain of Tr_1 is 150, the gain of Tr_2 is 30. Calculate:

a) the overall gain of the Darlington pair;
b) the base current required to give a current of 100 mA through the load resistor.



ASSIGNMENT 1.11

When a signal is sent from a logic sub-system is high (5V), a driver sub-system supplies current to a solenoid valve. The driver sub-system is shown below.



(a) Calculate the current flowing into the base of the transistor when the control signal is high.

The transistor should saturate when the control signal is high. At saturation V_{CE} is 0.2V.

(b) Calculate the minimum current gain required to operate the solenoid under these conditions.

The circuit was modified in order to reduce the current flowing from the logic sub-system. The current gain of the driver sub-system was then 800.

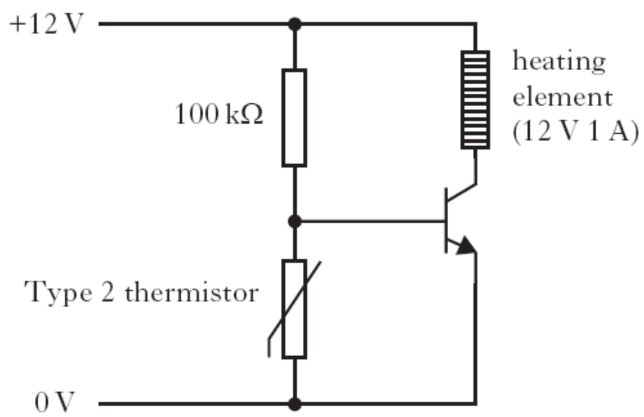
The operating characteristics of the transistors available are shown in the table below

Device	Case style	IC (max) mA	h_{FE}
BC108	T0-18	200	100
BFY51	T0-39	1000	40
TIP31A	T0-220	3000	10
BC142	T0-39	1000	20

(c) Draw a modified circuit diagram for a driver sub-system with the required current gain. Clearly label every device used.

ASSIGNMENT 1.12

The circuit shown below is designed to switch on a greenhouse heater when the temperature in the greenhouse falls to 15°C.



(a) Calculate, for a temperature of 15°C with the transistor switched on and saturated;

(i) The current flowing through the 100kΩ resistor;

(ii) The current flowing through the thermistor;

(iii) the current flowing into the base of the transistor.

The heating element is rated at 12V,1A.

(b) Calculate the minimum current gain, h_{FE}, required for the heating element to fully switch on at 15°C.

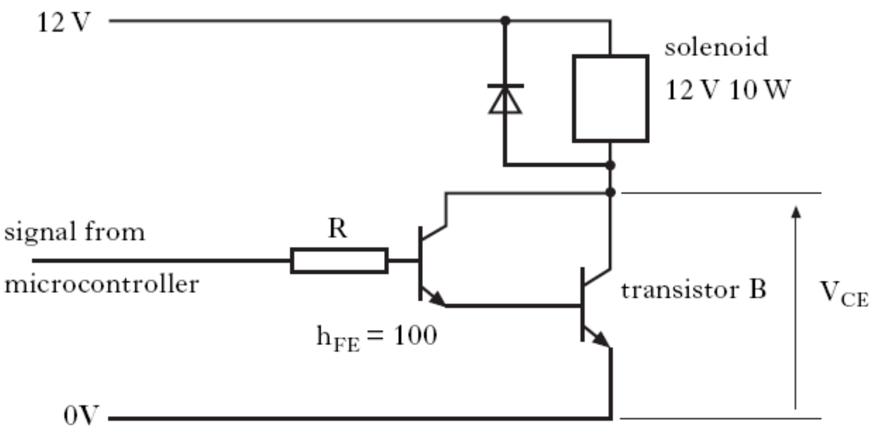
As the required gain could not be achieved with a single transistor, the circuit was modified bt substituting a Darlington pair with an overall h_{FE} of at least 40,000. The following transistors were available.

TRANSISTOR	h_{FE}	$I_{c(max)}$ (A)
A	450	0·1
B	300	0·5
C	100	1
D	50	2

(c) Draw a suitable Darlington pair. Label each transistor in the Darlington pair with the appropriate letter from the table above.

ASSIGNMENT 1.13

A water valve is operated by a solenoid, which is controlled by the circuit shown below. When the transistors are switched on and saturated, V_{CE} = 0.8V. The maximum current that can be drawn from the microcontroller is 0.12mA.



(a) Calculate the minimum current gain for transistor B to ensure saturation.

A transistor with a current gain of 80 is chosen for transistor B.

(b) Calculate the minimum base current necessary to cause saturation.

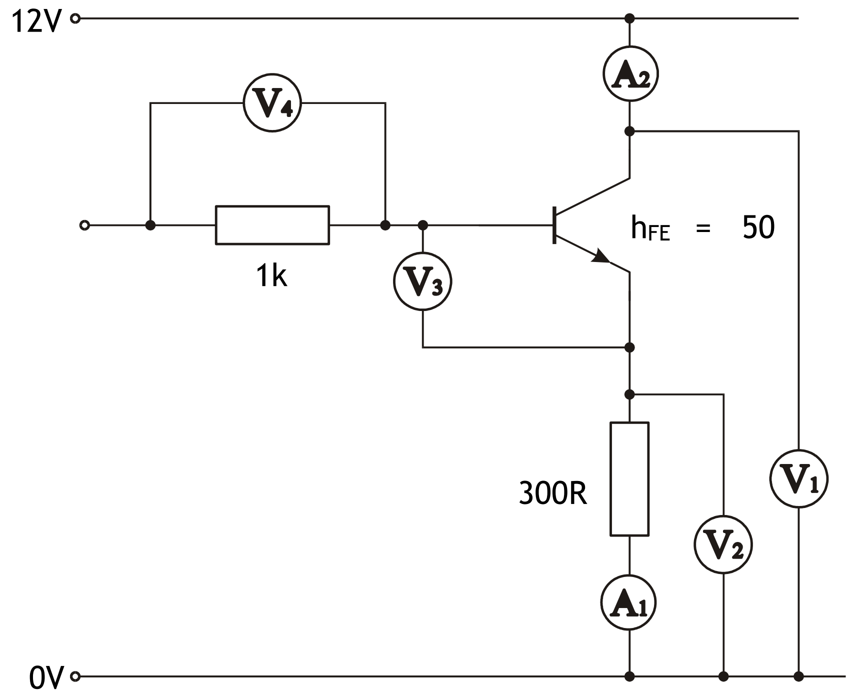
The signal from the microcontroller is 5V when the solenoid is activated.

(c) Calculate the value of base resistor R necessary to limit the base current to 0.12mA.

ASSIGNMENT 1.14

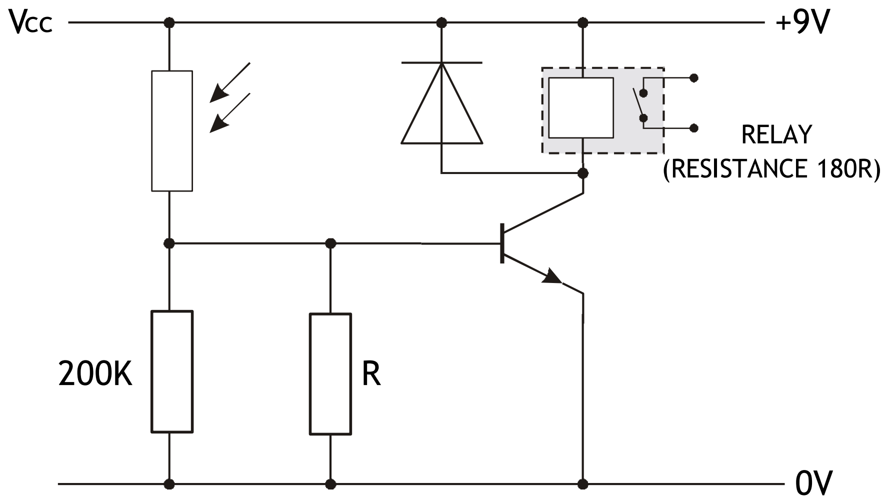
The following electronic system is set up for a test with various ammeters and voltmeters connected as shown below. In the condition shown, the transistor is fully saturated with a base current of 500 μA.

Write down the readings which you would expect to see on each of the four voltmeters (V_1 - V_4) and the two ammeters (A_1 - A_2).



ASSIGNMENT 1.15

A designer is asked to construct an electronic circuit which will energise a relay at a set light level. Having investigated the characteristics of the light transducer, she finds that the resistance of the transducer at “switch on” level is 2.1 M Ω. The proposed design is shown below. The transistor saturates when V_{be} = 0.6V.



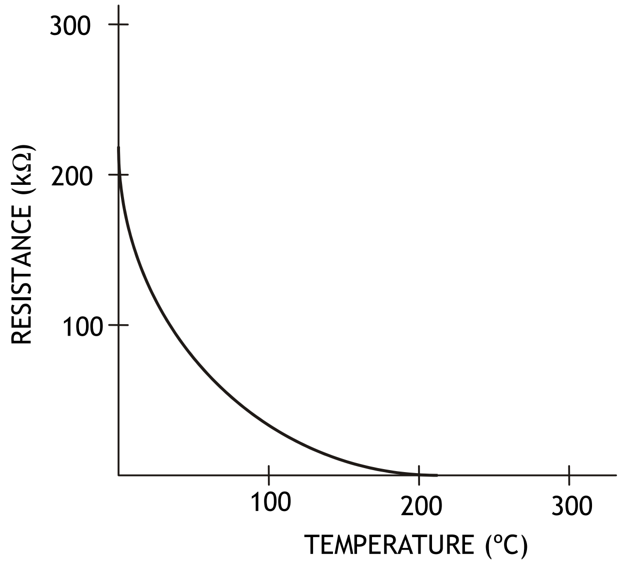
Determine, assuming the transistor is in a fully saturated condition:

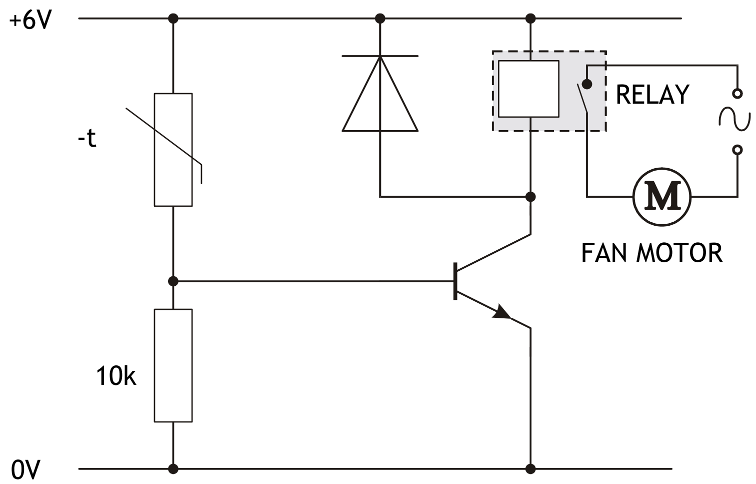
(a) the value of the unknown resistor R required to make the transistor operate correctly;

(b) the power dissipated in the relay coil.

ASSIGNMENT 1.16

The control circuit for a cooling fan is based on a thermistor. The graph shows the operating characteristics of the thermistor and the figure below shows the proposed circuit diagram.





(a) (i) The motor should switch on when V_{be} = 0.6V. For this condition, calculate the value of R_t.

(ii) From the graph, determine the temperature at which the fan **should** switch on.

(b) When the circuit is built and tested, it is found that the relay does not operate at the switch - on temperature.

(i) Suggest **one** reason why the transistor fails to operate the relay.

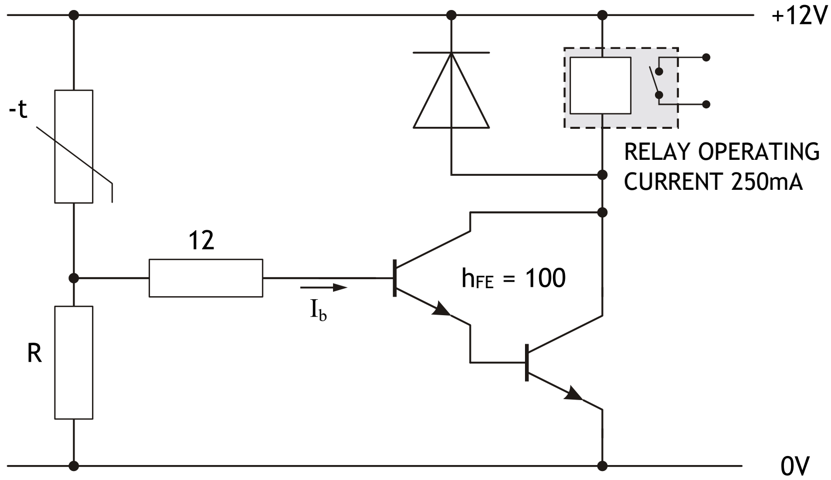
(ii) **Redraw** the circuit diagram to show how a Darlington pair could be used to overcome this problem.

ASSIGNMENT 1.17

An instant electric shower is designed to deliver water at a fixed temperature from a cold water supply.

An additional safety feature is to be added which will switch off the power to the shower if the water temperature produced by the heating element becomes dangerously high (greater than 50 °C).

The diagram below shows the proposed safety system circuit. The relay requires an operating current of 250 mA. The resistance of the thermistor at 50°C is 1 kΩ .



a) Name the transistor configuration used in this circuit.

b) State one advantage of using this configuration.

c) For the relay to operate:
calculate the base current, I_b;

(i) calculate the potential difference across the 12kΩ resistor;
(ii) determine the voltage across the fixed resistor R;
(iii) calculate the value of R.

The Push-Pull Amplifier

NPN bipolar transistors and n-type enhancement MOSFETs operate when the base or gate is made positive with respect to the zero volt line.

PNP and p-type MOSFETs operate off negative signals.

A push-pull amplifier consists of one of each type of bipolar transistor (or MOSFET) connected in series with a + and - supply rail.

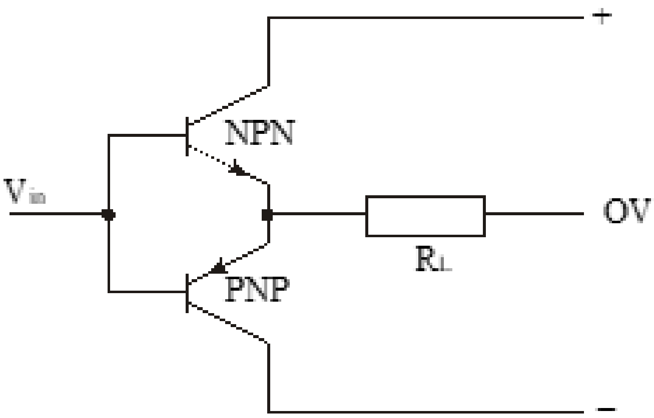


fig 35

If V_{in} is Positive with respect to 0V, the NPN transistor will switch on, current will flow from the + supply line through the collector-emitter junction, through the load resistor down to the 0Volt line

If V_{in} is Negative with respect to 0V, the PNP transistor will switch on, current will flow from the 0Volt line through load resistor, through the emitter-collector junction, to the + supply line.

The direction of current flow through the load resistor will therefore depend on whether the input voltage is positive or negative. If the load resistor is replaced by a motor, the direction of rotation of the motor can be altered dependent on the input voltage.

Circuit Simulation Software.

Using Crocodile Clips or another similar software package construct the following circuit.

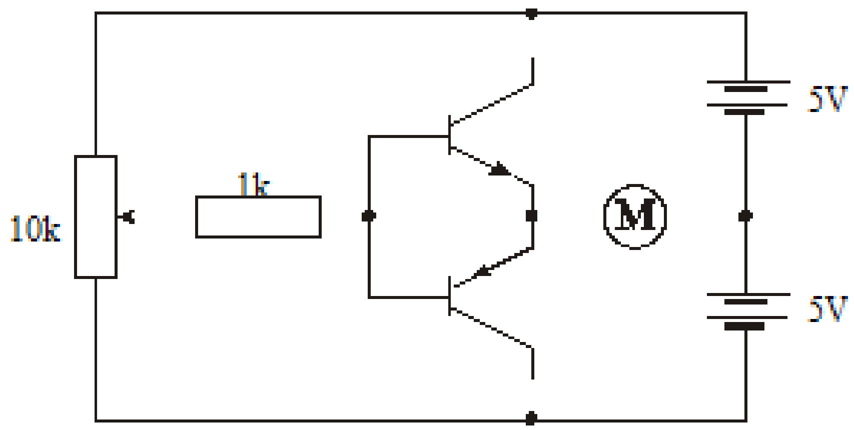
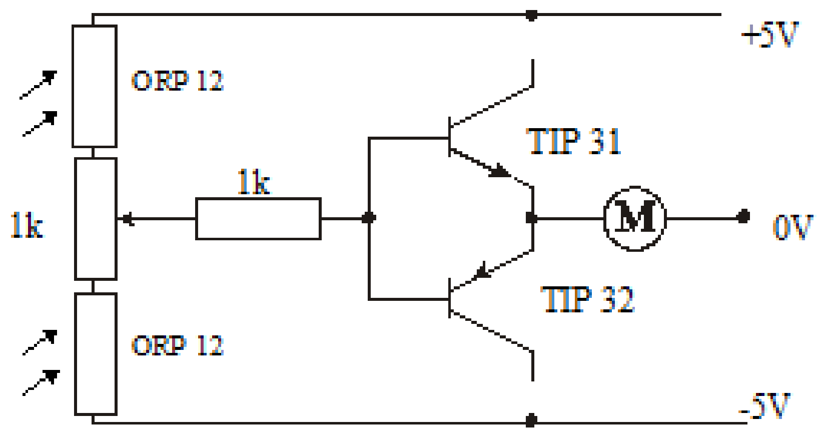


fig 36

Investigate what happens when the potentiometer slider is altered.

Construct the circuit shown below onto breadboard.

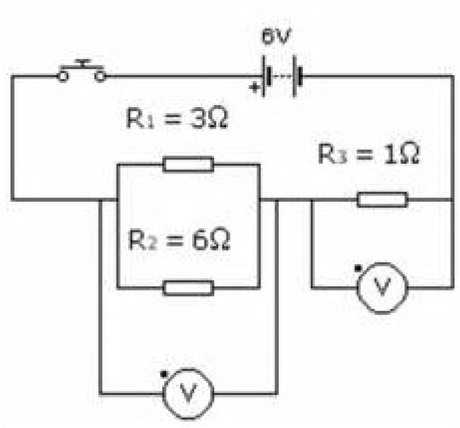


Adjust the variable resistor until the motor is stationary.
Investigate what happens when you shade each LDR in turn.

Homework – 1.1

For the conditions in the circuit below calculate;

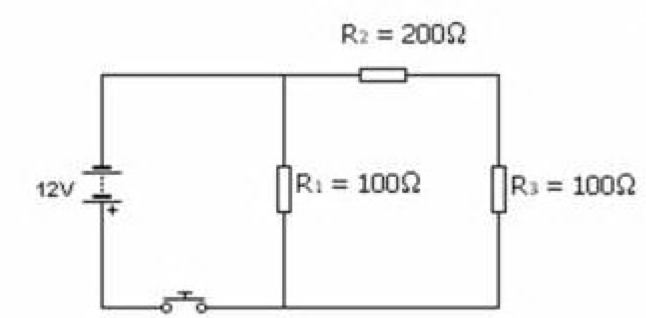
(a) the combined resistance of R_1 and R_2.
(b) the total resistance of the network R_1, R_2 and R_3
(c) the current 'I' supplied by the battery.
(d) the Voltage dropp V_p, across the parallel resistors R_1 and R_2 and the Voltage drop, V_3 across R_3.
(e) the current I_1 flowing in R_1 and I_2 flowing in R_2.



Homework – 1.2

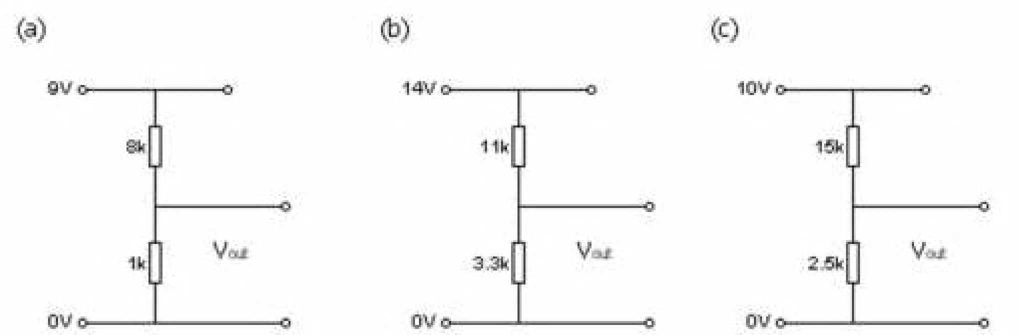
For the circuit below calculate;

a) the total resistance in the circuit.
b) the voltage drop across R_2 and the voltage drop across R_3.
c) the current flowing in each resistor I_1, I_2 and I_3.

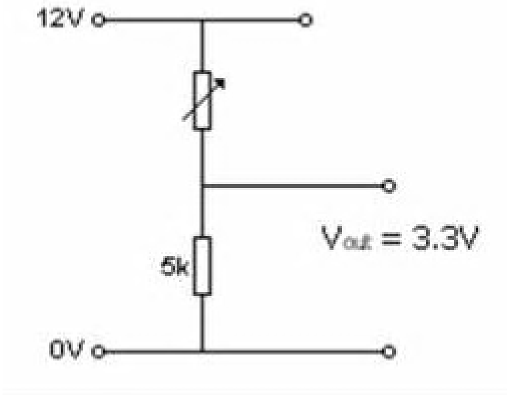


Homework – 1.3

(a) Calculate the output voltage for each of the potential divider circuits shown below

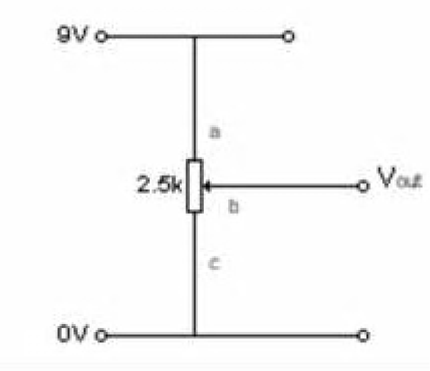


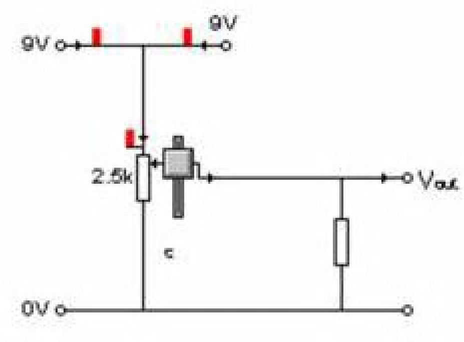
(b) Calculate the variable resistor setting in the potential divider shown.



Homework - 1.4

A 2.5k linear potentiometer is used as a potential divider for a 9V supply
The ‘wiper’ on the ‘pot’ is set at B, a point four fifths of the way along the track from point C at the end of the potentiometer.

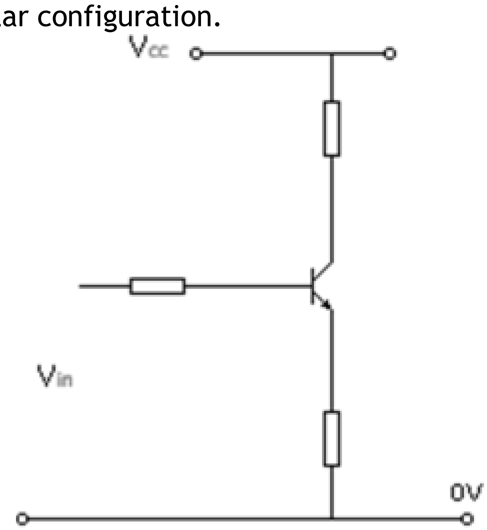




(a) What is the resistance of length B, C of the track.
(b) What is the output voltage V_{out} at this setting.
(c) If a resistor is now connected as a ‘load’ across the output as shown in figure 1.4.2, what effect will this have on the output voltage when
  (i) the load resistance is 20k and,
  (ii) when the load resistance is 2k.
  (iii) Comment on your findings.

Homework - 1.5

The circuit below shows a diagramatic sketch of a simple bi-polar configuration.



(a) Copy the diagram and complete the transistor symbol to represent an N.P.N device and identify.

  (i) the emitter
  (ii) the base
  (iii) the collector.

(b) Label the diagram showing
 (i) V_b – base voltage relative to ground.
 (ii) V_e – emitter voltage relative to ground.
 (iii) V_{ce} – voltage between collector and emitter junctions.
 (iv) V_{be} – voltage between base and emitter junctions.
 (v) V_l – voltage across load resistor.

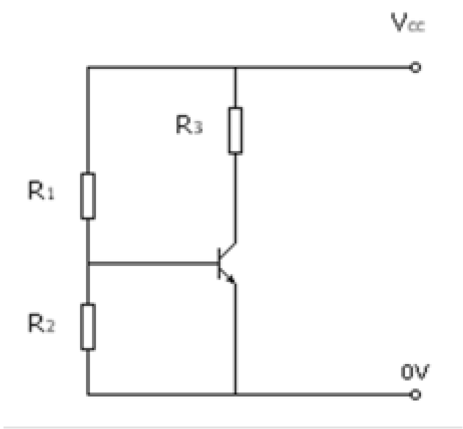
(c) On the diagram clearly show the conventional current flow for;
 (i) I_c - collector current.
 (ii) I_b - base current.
 (iii) I_e - emitter current.

(d) Clearly descibe the operation of the transistor explaining what is meant by 'saturation'.

Homework - 1.6

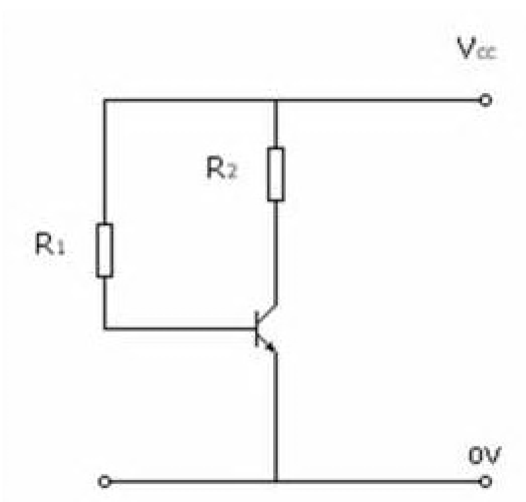
In the circuit shown below state whether the transistor will be switched on if,

(a) R_1 = 10k ; R_2 = 1k ; V_{cc} = +4.5V
(b) R_1 = 10k ; R_2 = 100k ; V_{cc} = +4.5V
(c) R_1 = 4k7 ; R_2 = 10k ; V_{cc} = +15V
(d) R_1 = 2k2 ; R_2 = 10k ; V_{cc} = +24V



Homework - 1.7

In the circuit shown below the base emitter junction voltage V_{be} is 0.7V.



(a) If Vcc = +4.5V, Ic = 25mA and R1 = 3k9, calculate
  (i) the base current Ib.
  (ii) the current gain AI.

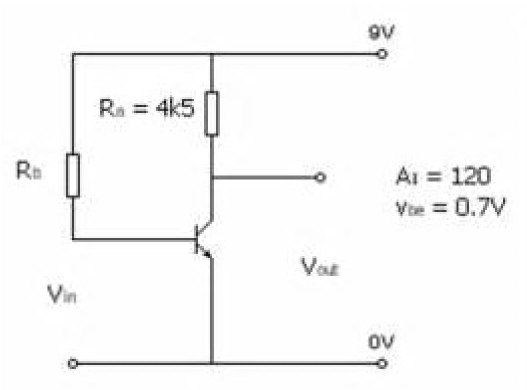
(b) If Ib = 20μA and Ic = 2mA and Vcc = 9V, calculate;
  (i) R1
  (ii) R2
  (iii) AI

(c) If Vcc = 6V, R1 = 100k, R2 = 1k, calculate
  (i) the P.D. across R1
  (ii) Ib
  (iii) Ic if hfe = 60
  (iv) The P.D across R2

(d) If Vcc = 6V and Ib = 20μA, calculate the value of R1

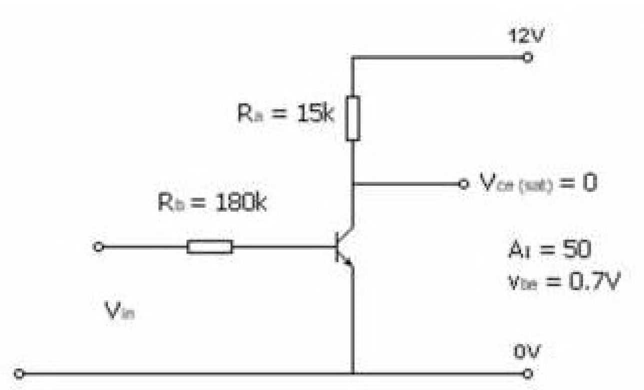
Homework - 1.8

In the circuit shown below calculate the value of Rb if the base current is 10μA.



Determine also the output voltage V_{out}.

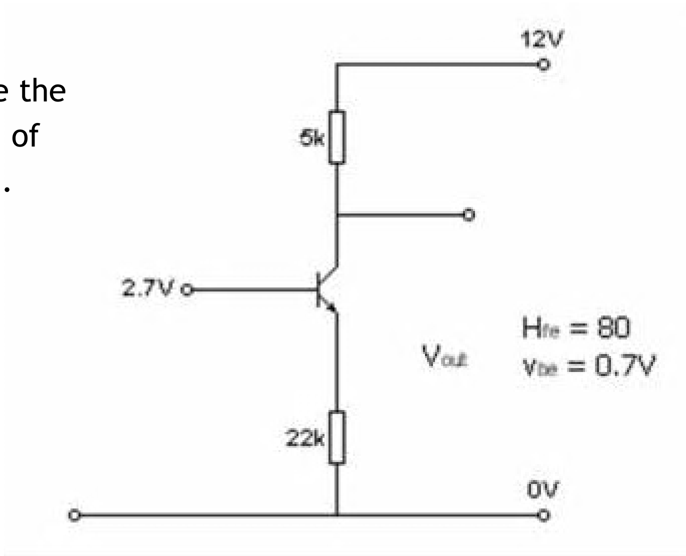
Homework - 1.9



In the circuit above determine the value of I_c, I_b and V_i which will result in saturation of the transistor.

Homework - 1.10

In the circuit shown below calculate the output voltage and the voltage gain of the circuit for the conditions shown. State any assumptions you make.



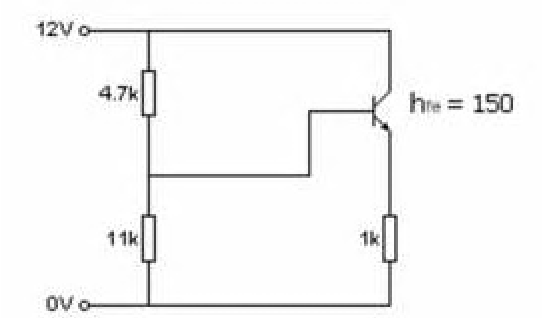
Homework - 1.11

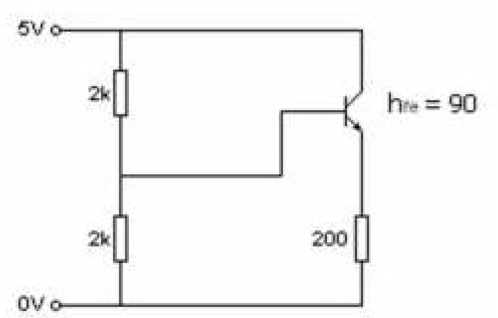
For each of the six simple transistor circuits shown below, calculate;

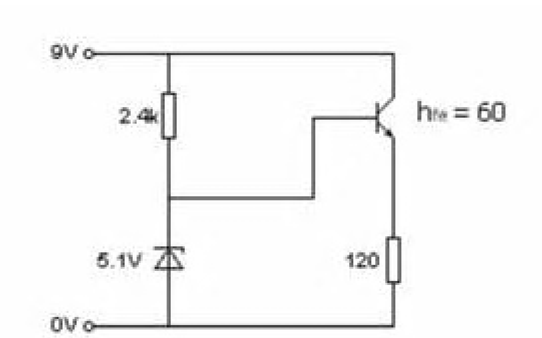
(a) the emitter voltage; (Ve)

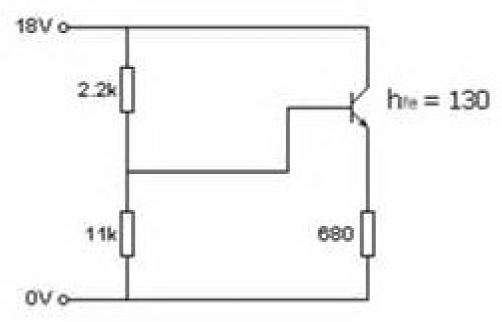
(b) the emitter current (Ie);

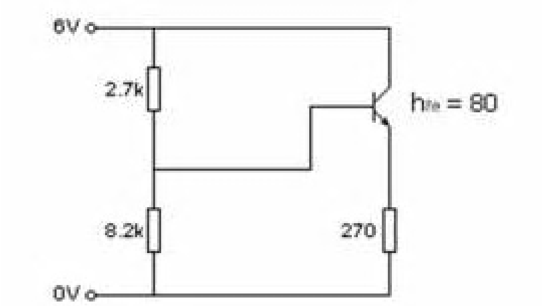
(d) the base current (Ib).

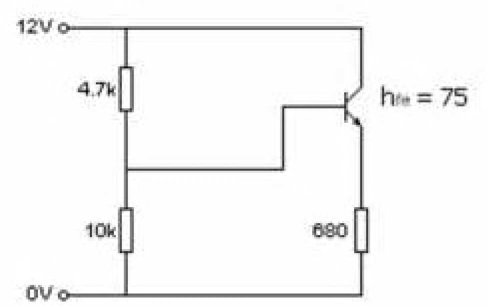






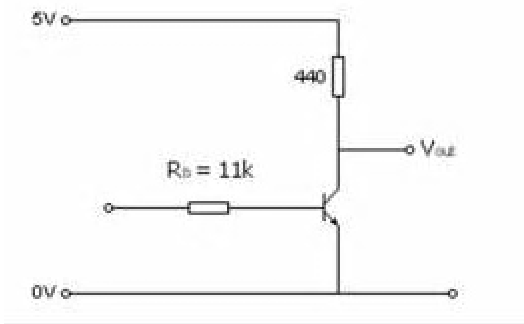






Homework – 1.12

In the circuit shown, the transistor has a gain of 50.
Calculate the values of;



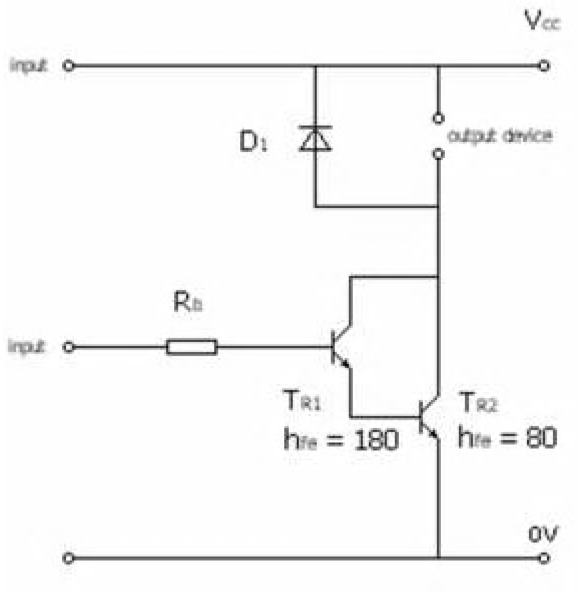
(i) base current, *Ib*;

(ii) the collector current, *Ic*;

(iii) V out, for each value of Vin given.

Homework – 1.13

The diagram below is part of a circuit which is suitable for processing the input from various types of sensors and providing an appropriate output.



(a) (i) Name the switching circuit shown and describe its operation and advantage.

(iii) State the overall gain hfe for the arrangement.

(b) State the purpose of the diode D1 in the circuit.

(c) For each of the applications given below, sketch the input part of the circuit diagram that would be suitable and the output device which would be appropriate.

(i) Thermostat for the aquarium.

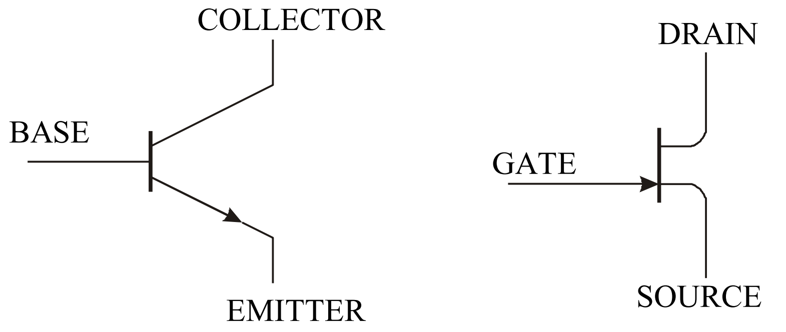
(ii) A rain detector to automatically close skylights.

(iii) A window “open” alarm.

(iv) Automatic window shades for bright sunlight.

MOSFETS

Although the base current in a transistor is usually small (< 0.1 mA), some input devices (e.g. a crystal microphone) may be limited in their output. In order to overcome this, a Field Effect Transistor (FET) can be used.



BIPOLAR TRANSISTOR

FIELD EFFECT TRANSISTOR

Applying a voltage to the Gate connection allows current to flow between the Drain and Source connections.

This is a Voltage operated device. It has a very high input resistance (unlike the transistor) and therefore requires very little current to operate it (typically 10-12 A).

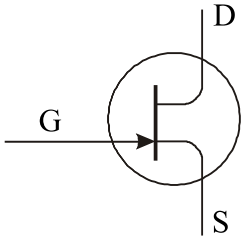
Since it operates using very little current, it is easy to destroy a FET just by the static electricity built up in your body.

FET's also have the advantage that they can be designed to drive large currents, they are therefore often used in transducer driver circuits.

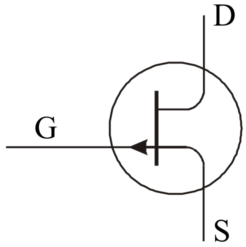
Two different types of FET's are available:
JFET (Junction Field Effect Transistor); and
MOSFET (Metal Oxide Semiconductor Field Effect Transistor).

All FET's can be N-channel or P-channel.

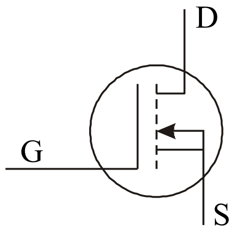
MOSFET's can be "depletion type" or "enhancement type".



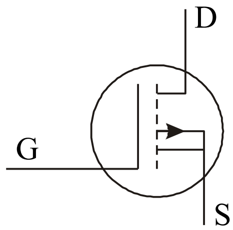
N-CHANNEL JFET



P-CHANNEL JFET



N-CHANNEL
ENHANCEMENT
MOSFET



P-CHANNEL
ENHANCEMENT
MOSFET

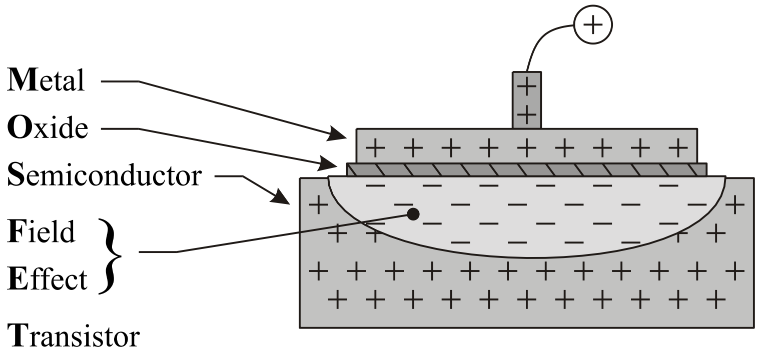
The simplicity in construction of the MOSFET means that it occupies very little space. It can also be designed to be used as a resistor or capacitor.
Because of its small size, many thousands of MOSFET’s can easily be incorporated into a single integrated circuit. The high input resistance means extremely low power consumption compared with bipolar transistors.
All these factors mean that MOS technology is widely used within the electronics industry today.

Enhancement-type MOSFET's can be used in a similar way to bipolar transistors.

N-channel enhancement MOSFET’s allow a current to flow between Drain and Source when the Gate is made Positive (similar to an NPN transistor).
P-channel enhancement MOSFET’s allow a current to flow between Drain and Source when the Gate is made Positive (similar to an PNP transistor).

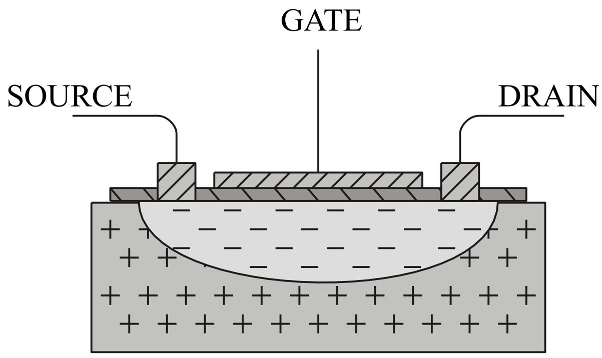
N-channel enhancement MOSFET - theory

The MOSFET transistor is constructed on a piece of p-type Semiconductor, an Oxide insulating layer separates this from the Metal 'Gate' contact.



Making the metal contact positive will produce a Field, repelling the positive majority carriers leaving negatives behind (to produce an N-channel).

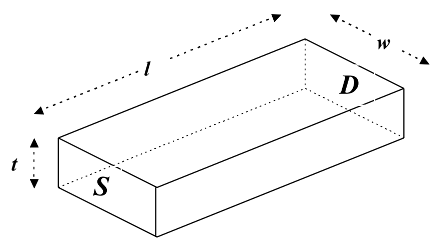
If the field produced by the Gate voltage is large enough, a channel is produced connecting the Drain and Source. When a voltage is applied between the Drain and Source, current will flow along the channel.



(In practice, the Drain and Source metal plates are connected to n-type semiconductor within the p-type substrate).

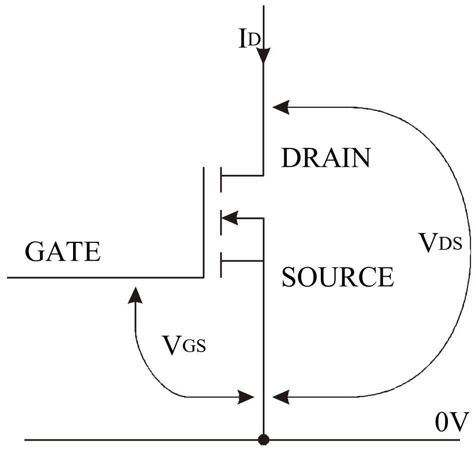
The channel acts as a resistance between the Source and Drain. The size of which depends on:

- the length (l) of the channel between D and S
- the width (w) of the channel
- the thickness (t) of the channel



l and *w* are determined during manufacture of the MOSFET, *t* is adjusted by altering the gate voltage.

For a given MOSFET, the size of the current between the Drain and Source will therefore depend on the Gate voltage (V_{GS}) and the voltage between the Drain and Source (V_{DS}).



Like a bipolar transistor, if the Gate voltage is below a certain level (the threshold value, V_T), no current will flow between the Drain and Source (the MOSFET will be switched off).

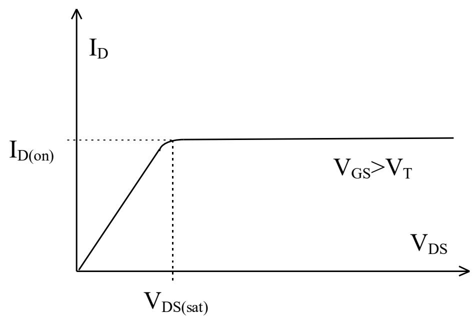
If the Gate voltage is above V_T, the MOSFET will start to switch on.
Increasing the Gate voltage will increase the thickness of the channel, increasing the number of charge carriers in the channel and hence increasing I_D.

For a given value of V_{GS} (above V_T), increasing V_{DS} increases the current until saturation occurs. Any further increase will cause no further increase in I_D. The MOSFET is fully ON and can therefore be used as a switch.

Saturation occurs when $V_{DS} = V_{GS} - V_T$.

If V_{DS} is $\geq V_{DSsaturation}$, I_D is constant (for a given value of V_{GS})
(I_D is then known as $I_{D(on)}$).

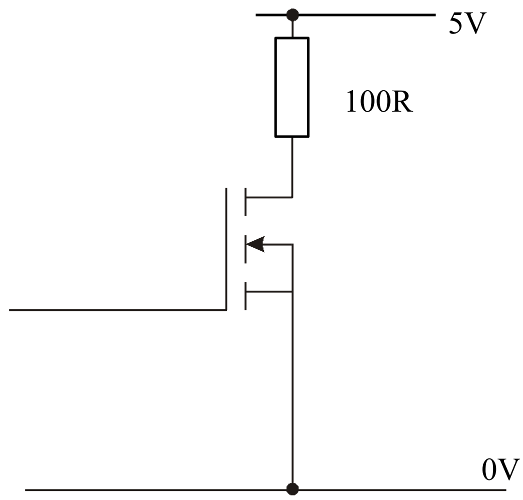
When saturation occurs $I_D = I_{D(on)}$



When saturation occurs, the resistance of the channel, R_{DS}, is normally low ($R_{DS(on)}$ less than 1Ω for power MOSFET's)

WORKED EXAMPLE

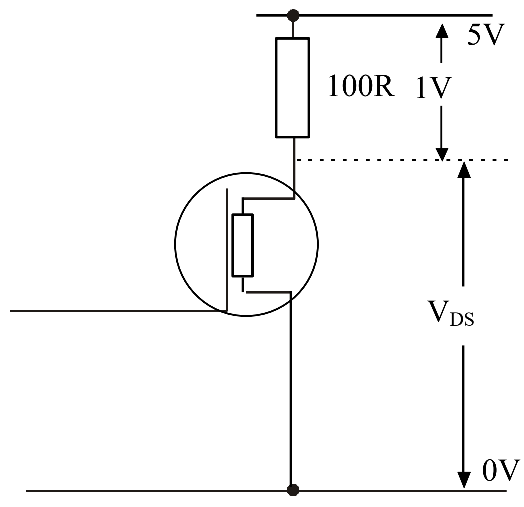
The threshold gate voltage for the MOSFET shown below is 2 V. Calculate the gate voltage required to ensure that a saturation current of 10 mA flows through the load resistor.



Step 1

The Drain - Source channel acts as a series resistor with the 100R, since the current is the same in a series circuit, the voltage over the 100R can be calculated using Ohm's law

V = IR = 10 mA x 100 = 1 Volt



Step 2

Using Kirchoff's 2nd law,

the voltage over the channel + the voltage over the load resistor = supply voltage

hence V_{DS} = 5 - 1 = 4 Volts

Step 3

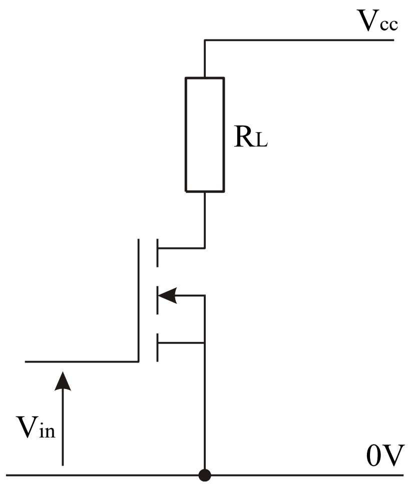
For saturation to occur,

$V_{DS} = V_{GS} - V_T$

$V_{GS} = V_{DS} + V_T$

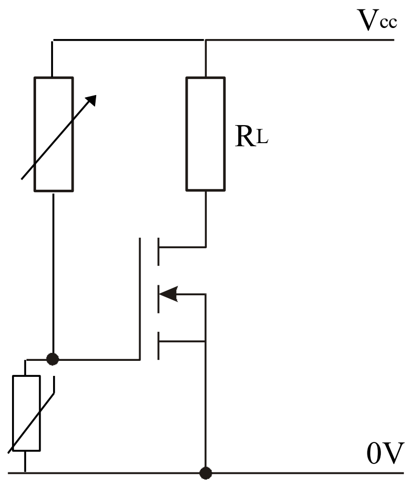
$V_{GS} = 4 + 2 =$ **<u>6 Volts</u>**.

MOSFET's can be designed to handle **very high drain currents**, this means that they can be used to drive high current output transducers drivers without the need for relay switching circuits (unlike the bipolar transistor). MOSFET's connected as shown below are said to be in common-source mode (c.f. common-emitter mode for bipolar transistors).



The load resistor could be any output transducer, bulb, motor, relay etc. Since MOSFET's are particularly sensitive to high voltages, care must be taken to include a reverse biased diode over transducers that may cause a back emf when switched off.

A variable resistor can be used in a voltage divider circuit and adjusted to ensure that the input voltage to the gate = V_T



Changes in V_{GS} (ΔV_{GS}) above the threshold value causes changes in I_D (ΔI_D)
Whereas the performance of a bipolar transistor is measured by its' amplification (h_{fe}), the performance of a FET is measured by its *transconductance* (g_m) and is calculated by

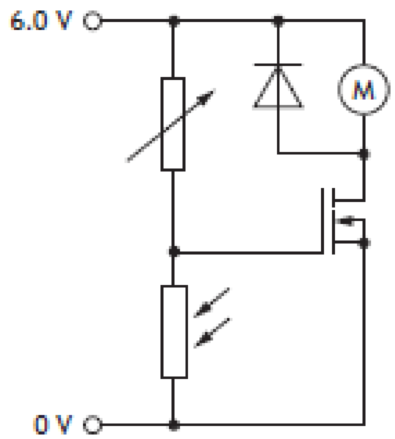
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

g_m is measured in Amps per Volt (AV^{-1})
[These units are sometimes referred to as siemens or mhos]

2023 Past Paper

9. (continued)

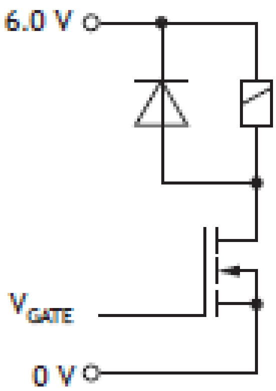
An alternative motor with a MOSFET driver is also considered. The MOSFET has a resistance of 2.3 Ω when fully saturated and the motor is rated as 0.40 W at 6.0 V.



(c) Calculate the drain-source current when the MOSFET is fully saturated. **3**

10. (continued)

In order to use a microcontroller-based system, solenoid valves need to be used. The following circuit has been designed to actuate one of the solenoids.



The solenoid is rated 12 W at 6.0 V. The MOSFET has a resistance of 0.70 Ω when switched on.

(d) (i) Calculate the resistance of the solenoid. **1**

(ii) Calculate the current through the MOSFET when it is fully switched on. **1**

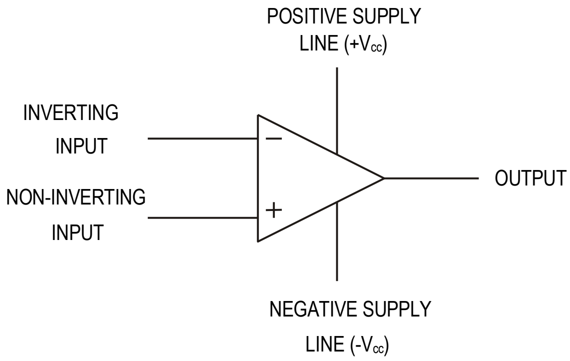
OPERATIONAL AMPLIFIERS

Circuits with specific designs can be constructed on a single piece of silicon chip. These are known as **i**ntegrated **c**ircuits.

One such ic is known as an operational amplifier **- op. amp**.

This ic was designed to perform mathematical operations.
The op. amp. can be used to add, subtract, multiply, divide, integrate and differentiate electrical voltages.
It can amplify both d.c. and a.c. signals.

The symbol for an op. amp. is shown below.



The op. amp. is designed to amplify the difference between the two input voltages.

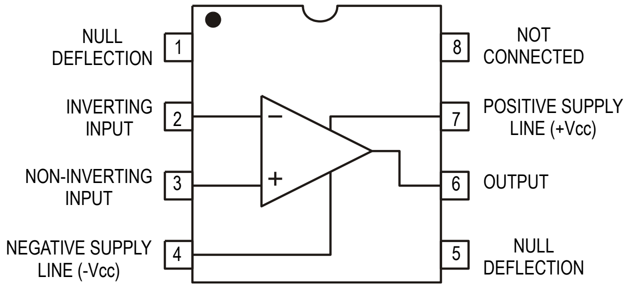
The two inputs are indicated by a "-" and "+".

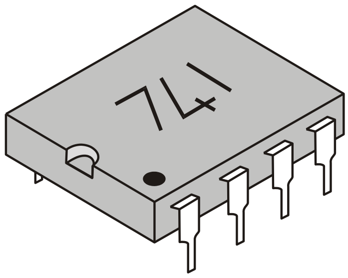
A positive signal to the "-" input is amplified and appears as a negative signal at the output. **- inverting input**

A positive signal to the "+" input is amplified and appears as a positive signal at the output. **- non inverting input**

If both inputs are exactly the same i.e. there is no difference, then the output should be zero.

It is normal practice to omit the power lines when drawing diagrams - these are taken for granted.





The top of any ic is usually indicated by a notch. Occasionally pin number 1 is indicated by a dot. Pins are always numbered from pin 1 in an anti - clockwise direction.

GAIN

The op. amp. was designed as a voltage amplifier.

The voltage gain of any amplifier is defined as

$$Voltage \quad gain = \frac{Voltage \quad output}{Voltage \quad input}$$

$$A_V = \frac{V_o}{V_i}$$

For a differential amplifier, the voltage input is the difference between the two inputs.

V_i = ($V_{\text{(at non - inverting input)}}$ - $V_{\text{(at inverting input)}}$)

ASSIGNMENT 2.01

a) If $V_{(at\ non\ -\ inverting\ input)}$ = 3.10 V and $V_{(at\ inverting\ input)}$ = 3.11 V. Calculate the input voltage and hence the output voltage if the gain is known to be 100.

b) The gain of an op. amp. is known to be 100,000. If the output voltage is 10 V, calculate the input voltage.

c) The gain of an op. amp. is known to be 200,000. If $V_{(at\ non\ -\ inverting\ input)}$ = 2.5 V and $V_{(at\ inverting\ input)}$ = 2.2 V, calculate the output voltage.

The answer to (c) is obviously unrealistic since the output voltage from an op. amp. cannot be greater than the supply voltage.

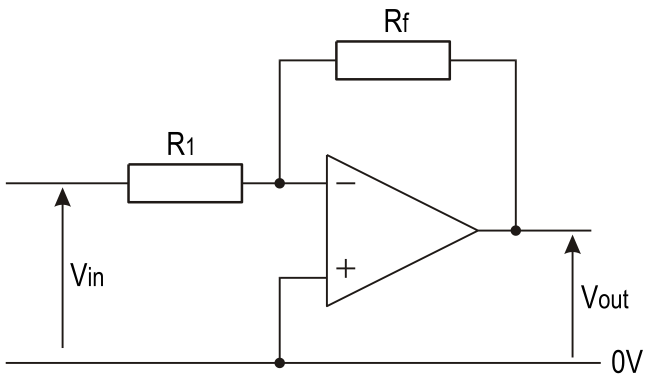
As the output of the op. amp. increases, saturation starts to occur and a "clipping" effect will be noticed. This normally occurs when the output reaches 85% of V_{CC}

Any further increase in the input will cause no further increase in the output since the op. amp. has reached saturation.

THE INVERTING AMPLIFIER CONFIGURATION

The signal is connected to the inverting input through an input resistor R_1.

The non - inverting input is connected to ground.



$$\text{voltage gain, } A_v = -\frac{R_f}{R_1}$$

WORKED EXAMPLE

A circuit configured as an inverting op amp with R_1 = 15 k and R_f = 470 k. Calculate the gain of the circuit and determine the output voltage when an input signal of 0.2 v is applied.

Step 1
Calculate the gain

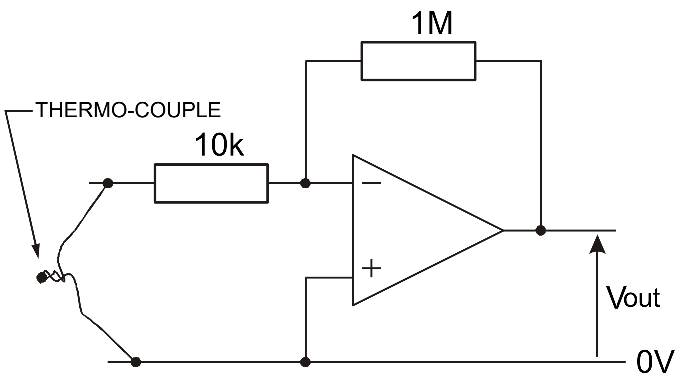
$$A_v = -\frac{R_f}{R_1} = -\frac{470k}{15k} = \underline{-31.33}$$

Step 2
Calculate the output voltage

$$V_{out} = A_v \times V_{in} = -31.33 \times 0.2 = \underline{-6.266\ V}$$

ASSIGNMENT 2.02

A thermocouple known to produce an output of 40 *m* volts per °C is connected to an op. amp.



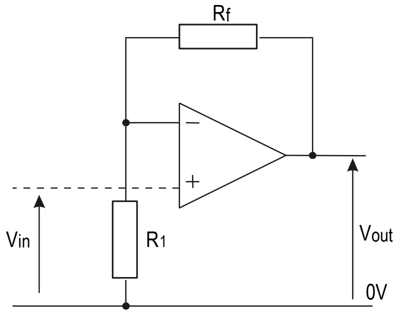
a) Calculate the gain of the circuit.

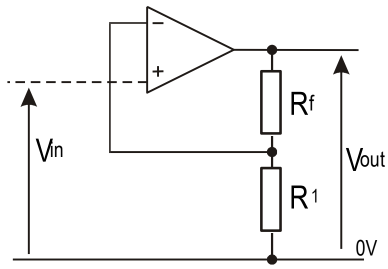
b) Determine the output voltage if the thermocouple is heated to a temperature of 1000 °C.

For an inverting amplifier, the sign of the output voltage is the opposite of the input voltage. In order to obtain the same sign, the output signal could then be fed through another inverter (with R_f = R_1, so that the gain = -1).

THE NON - INVERTING AMPLIFIER CONFIGURATION

The signal is connected directly to the non - inverting input.
R_f and R_1 form a voltage divider circuit feeding back some of the output signal to the inverting input.
The circuits below show two different ways of drawing the same circuit.

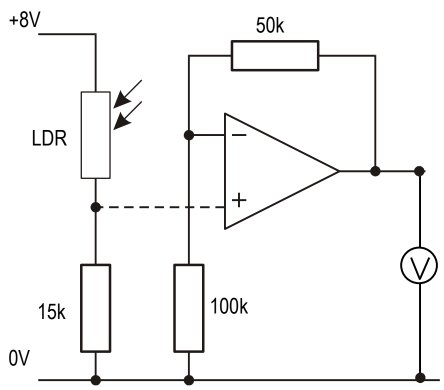




$$\text{voltage gain, } A_V = 1 + \frac{R_f}{R_1}$$

ASSIGNMENT 2.03

To build a simple light meter, a light dependent resistor (LDR) is connected into a circuit as shown below.



In bright sunlight, the LDR has a resistance of 1 k. In shade, it's resistance increases to 15 k.

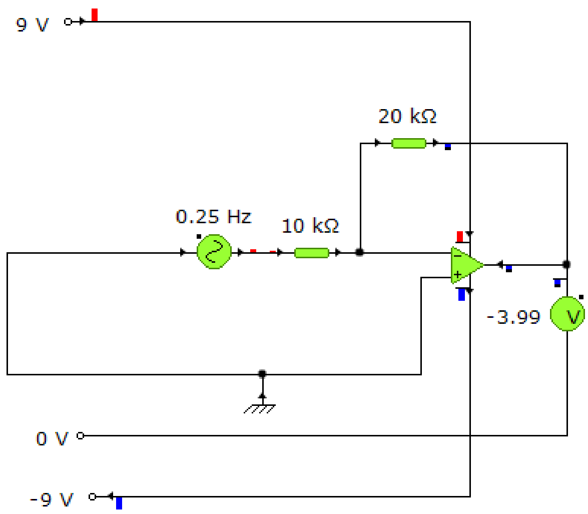
a) Determine the voltages that would appear on the voltmeter in both light conditions.
b) How could the circuit be altered to indicate changes in temperature?

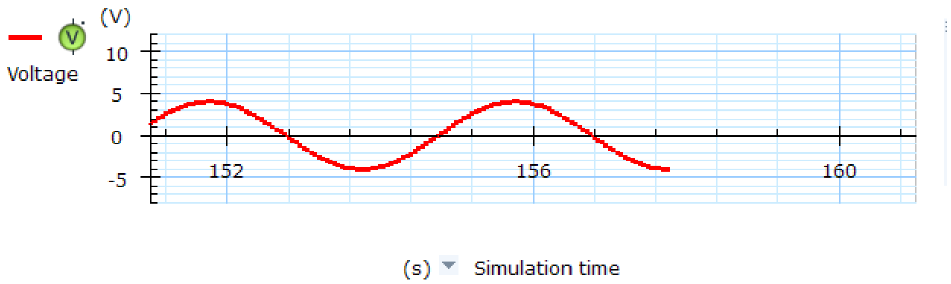
CIRCUIT SIMULATION SOFTWARE.

It is possible to use circuit simulation software such as Yenka to investigate electric and electronic circuits. Circuit simulation is widely used in industry as a means of investigating complex and costly circuits as well as basic circuits.

Circuit simulators make the modelling and testing of complex circuits very simple. The simulators make use of libraries of standard components along with common test equipment such as voltmeters, ammeters and oscilloscopes.

Construct the circuit shown below.





Set the input voltage to 2 Volts, 0.25 Hz.

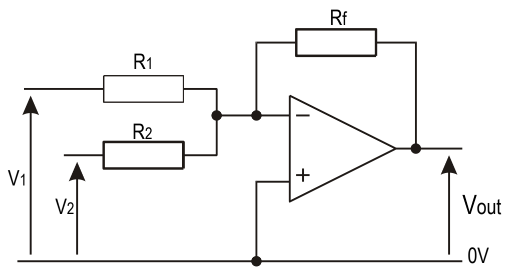
Set the oscilloscope to a maximum voltage of 10 V and a minimum voltage of -10 V

Start the trace on the oscilloscope and compare the input and output voltages.

Now increase the size of the feedback resistor to 50 k and repeat the exercise. This time you should observe “clipping” of the output signal.

THE SUMMING AMPLIFIER

Here, two (or more) signals are connected to the inverting input via their own resistors. The op. amp. effectively amplifies each input in isolation of the others and then sums the outputs.



Characteristics of the summing amplifier

Each input signal is amplified by the appropriate amount (see inverting mode)

$$V_{out} = (-\frac{R_f}{R} \times V_1) + (-\frac{R_f}{R} \times V_2) + \text{(any other inputs)}$$

Notes:

ñ any number of inputs can be added in this way.
ñ R_f affects the gain of every input.

$$V_{out} = (-\frac{R_f}{R} \times V_1) + (-\frac{R_f}{R} \times V_2) + \text{(any other inputs)}$$

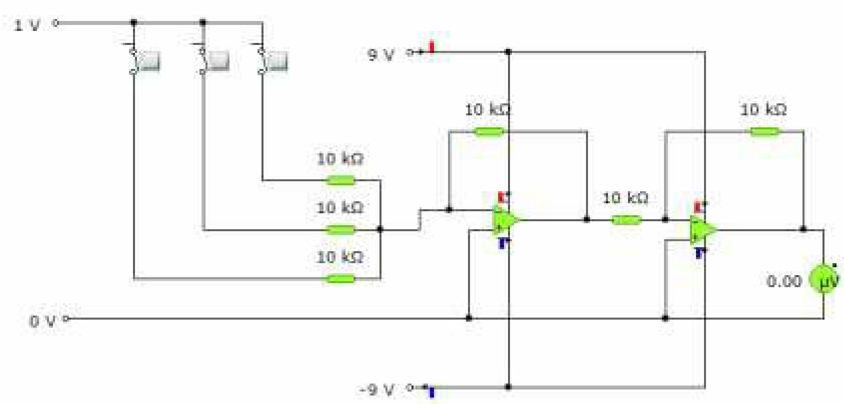
$$V_{out} = -R_f (\frac{V_1}{R_1} + \frac{V_2}{R_2} + ...)$$

CIRCUIT SIMULATION

1. Digital-to-analogue converter

Digital devices produce ON/OFF signals.

This circuit contains a summing amplifier and an inverting amplifier.



Since all inputs are amplified by the same amount (same value of input resistors) the output voltage = ƒ input voltages e.g. S1, ON (connected to 1V) and S2, ON (connected to 1V) , the output voltage should = (1 + 1) = 2V

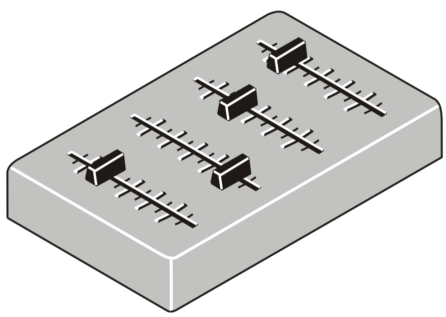
Now change the circuit so that R_2 = 5k and R_3 = 2.5k

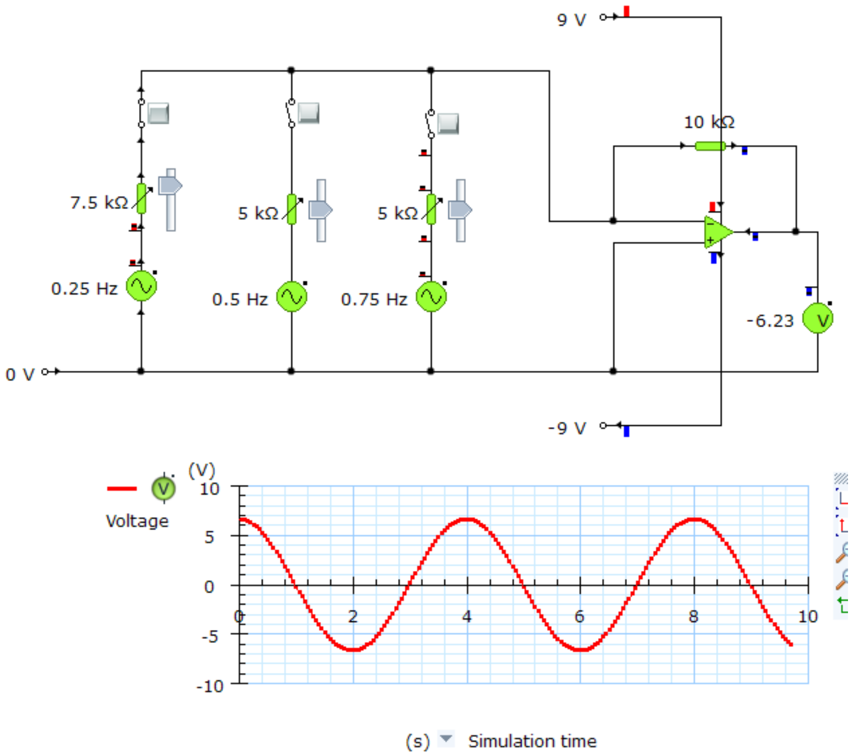
Copy and complete the following table to show the state of the input switches and the output voltage.

S3	S2	S1	output voltage (V)
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

2. a.c. mixer pre-amplifier

Mixers allow different signals to be amplified by different amounts before being fed to the main amplifier. Signals might come from microphones, guitar pick-ups, vocals, pre-recorded sound tracks etc.





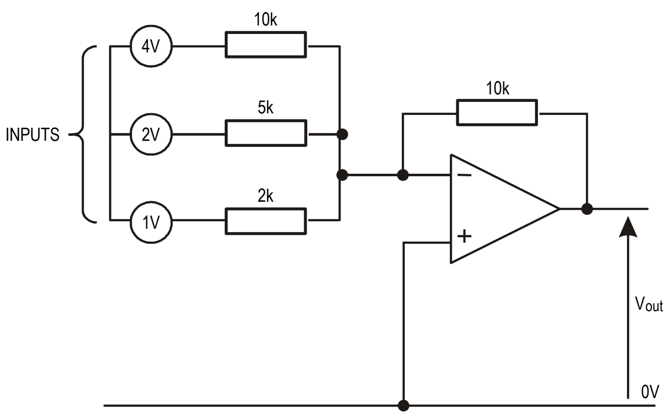
Putting each switch on individually will allow you to "see" each of the input signals in turn.

Putting more than one switch on at a time will show you the sum of the input signals.
Adjusting the size of the input variable resistors alters the amplification of that particular input signal.

Complex output signals can be constructed by adding sine waves of the correct amplitude and frequency - useful in electronic keyboards or synthesisers when a particular musical instrument is required.

ASSIGNMENT 2.04

Determine the output voltage for the circuit shown below.

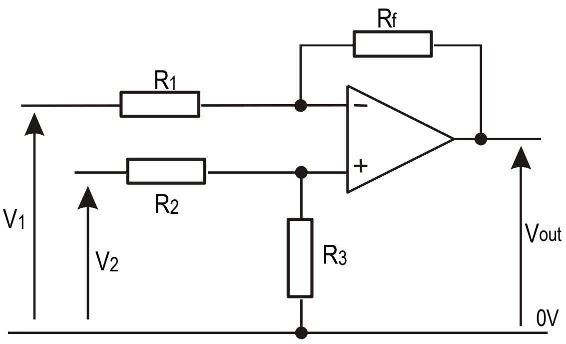


ASSIGNMENT 2.05

A personal stereo has both tape and radio inputs which produce output signals of 50 mV and 10 mV respectively. The amplifying system consists of a main amplifier and uses an op. amp. as a pre - amplifier. Design a possible pre - amplifier circuit so that an output of 1 volt is produced when either the tape or radio inputs are used.

THE DIFFERENCE AMPLIFIER CONFIGURATION

Here both inputs are used.
The op. amp. amplifies the difference between the two input signals.



To ensure that each input is amplified by the same amount, the circuit is designed so that the ratio:

$$\frac{R_f}{R_1} = \frac{R_3}{R_2}$$

To ensure that the input resistance of the circuit for each input is the same,

$$R_1 = R_2 + R_3$$

Characteristics of the difference amplifier

$$A_V = \frac{R_f}{R_1}$$

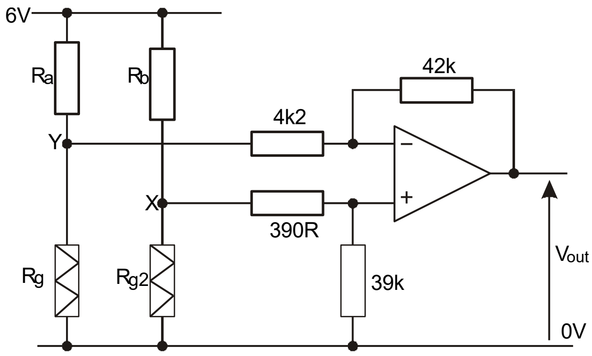
$$V_{out} = \frac{R_f}{R_1} \times (V_2 - V_1)$$

If $R_1 = R_f$ then $A_V = 1$ and $V_{out} = (V_2 - V_1)$, the circuit works as a "subtracter". the output will be zero if both inputs are the same.

This circuit is used when comparing the difference between two input signals.

ASSIGNMENT 2.06

Two strain gauges are connected to a difference amplifier as shown below.



$R_A = R_B = 1$ k, when not under strain, $R_{g1} = R_{g2} = 200$ W

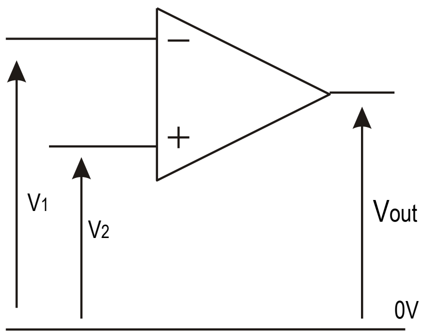
a) Calculate the voltage at X and Y when both gauges are not under strain and hence determine the output voltage of the amplifier.

b) As the strain of R_{g2} increases, its resistance increases from 200 to 210 W , determine the new output voltage.

c) What would you expect to happen to the output voltage if both gauges were put under the same amount of strain?

THE COMPARATOR CONFIGURATION

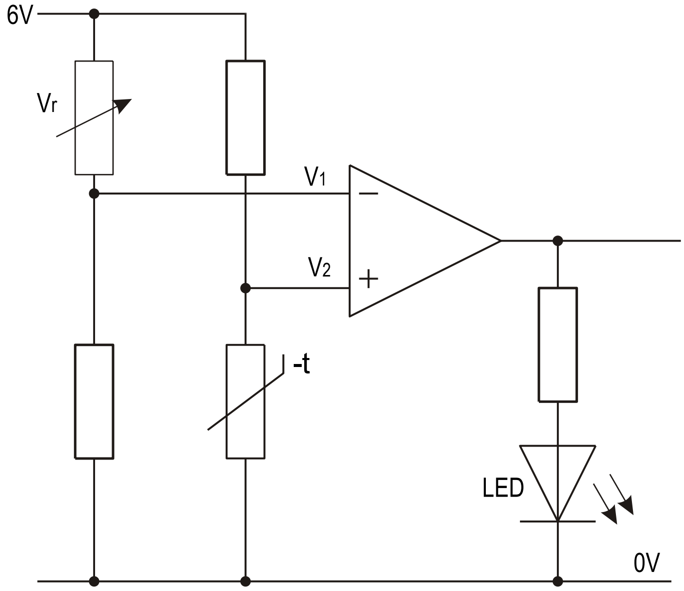
This is a special case of the difference amplifier in which there is no feedback. Any small difference in the two input signals is amplified to such an extent that the op. amp. saturates either positively or negatively.



if $V_2 > V_1$, V_{out} is **positive**, if $V_2 < V_1$, V_{out} is **negative**

This is commonly used in control circuits in which loads are merely switched on and off.

The circuit shown below would give an indication when the temperature falls below a preset value, 0^oC for example.



V_r is adjusted until V_1 is just greater than V_2, the output will therefore be negative and the led will be off.

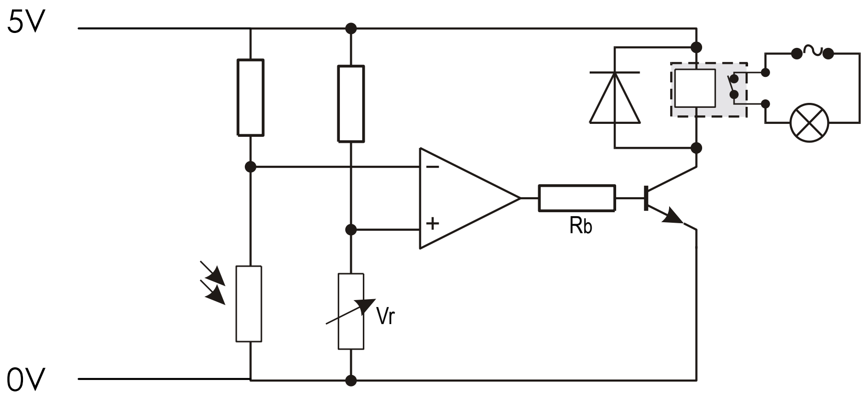
As the temperature falls, the resistance of the thermistor rises and therefore V_2 starts to rise. Eventually, $V_2 > V_1$, the output goes positive and the led lights.

DRIVING EXTERNAL LOADS

The maximum output current that can be drawn from an op. amp. is usually low (typically 5 mA). If larger currents are required, the output could be connected to a transducer driver either a bipolar transistor or MOSFET and relay circuit if required.

ASSIGNMENT 2.07

Describe the operation of the circuit shown and state the purpose of the variable resistor V_r and the fixed resistor R_b



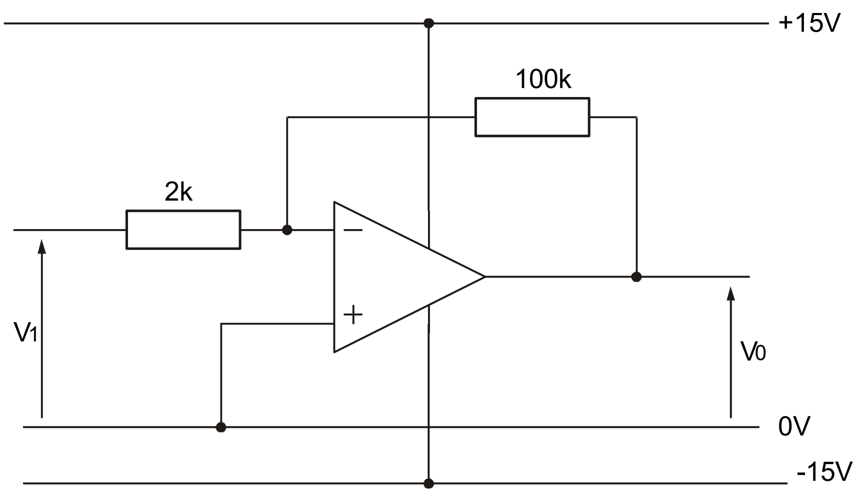
ASSIGNMENT 2.08

(a) Name the configuration of the amplifier shown below.

(b) Calculate the gain of the amplifier.

(c) (i) If the input signal V_i is 0.5 V, what is the value of the output signal V_o?

(ii) **Explain** your answer.



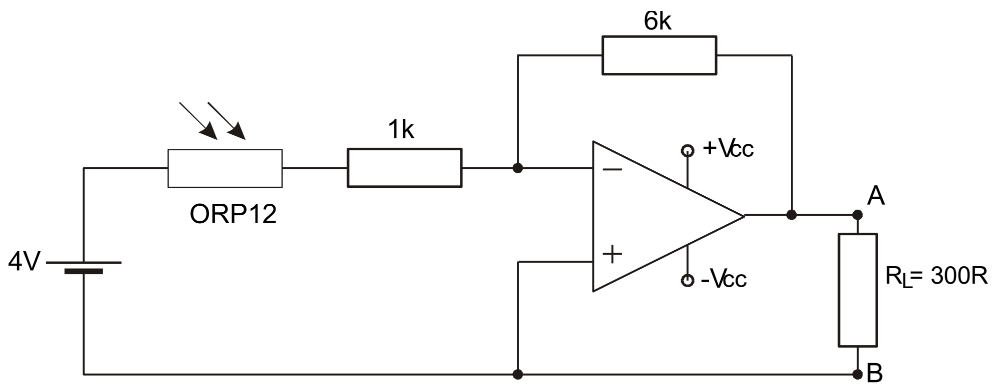
ASSIGNMENT 2.09

The op amp circuit below includes an ORP12 light dependent resistor as an input sensor.
When the light level on the LDR is 50 lux, determine:

(a) the resistance of the LDR;

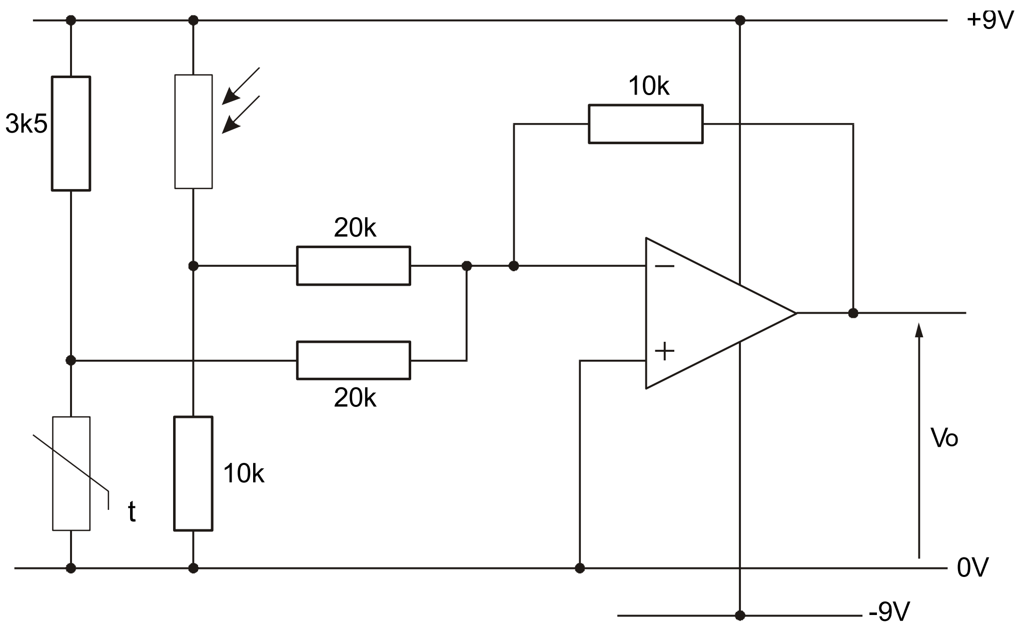
(b) the voltage gain of the operational amplifier;

(c) the current flowing through the load resistor R_L, stating clearly the direction in which it is flowing.



ASSIGNMENT 2.1

A technological experiment involves recording the total effects of light and temperature. It utilises an operational amplifier configured as shown below.



(a) Name the configuration of the amplifier used in the experiment.

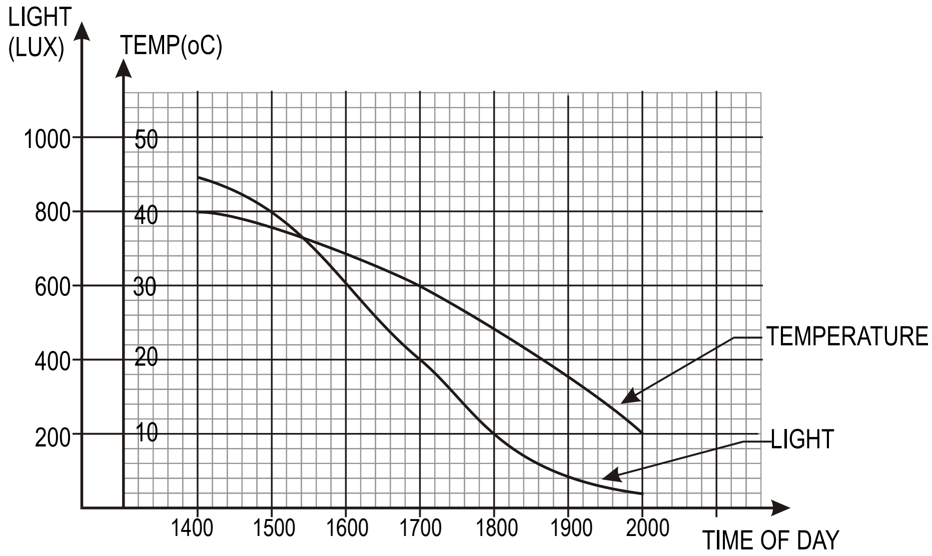
(b) Explain clearly how the system operates.

(c) Determine the gain of the amplifier.

(d) Comment on the suitability of the value of the gain in this particular circuit.

The following graph shows the actual temperature and light readings recorded during the experiment between the hours of 1400 and 2000 on one particular day.

The characteristics of the light dependent resistor and a type 3 thermistor used in the circuit are shown.



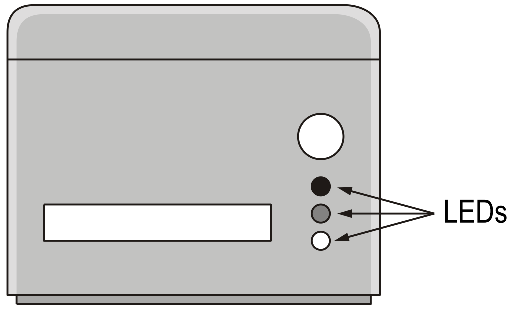
(e) Determine the output voltage (V_o) from the circuit at 1700 hours.

(f) For later processing, this value of (V_o) must be positive.

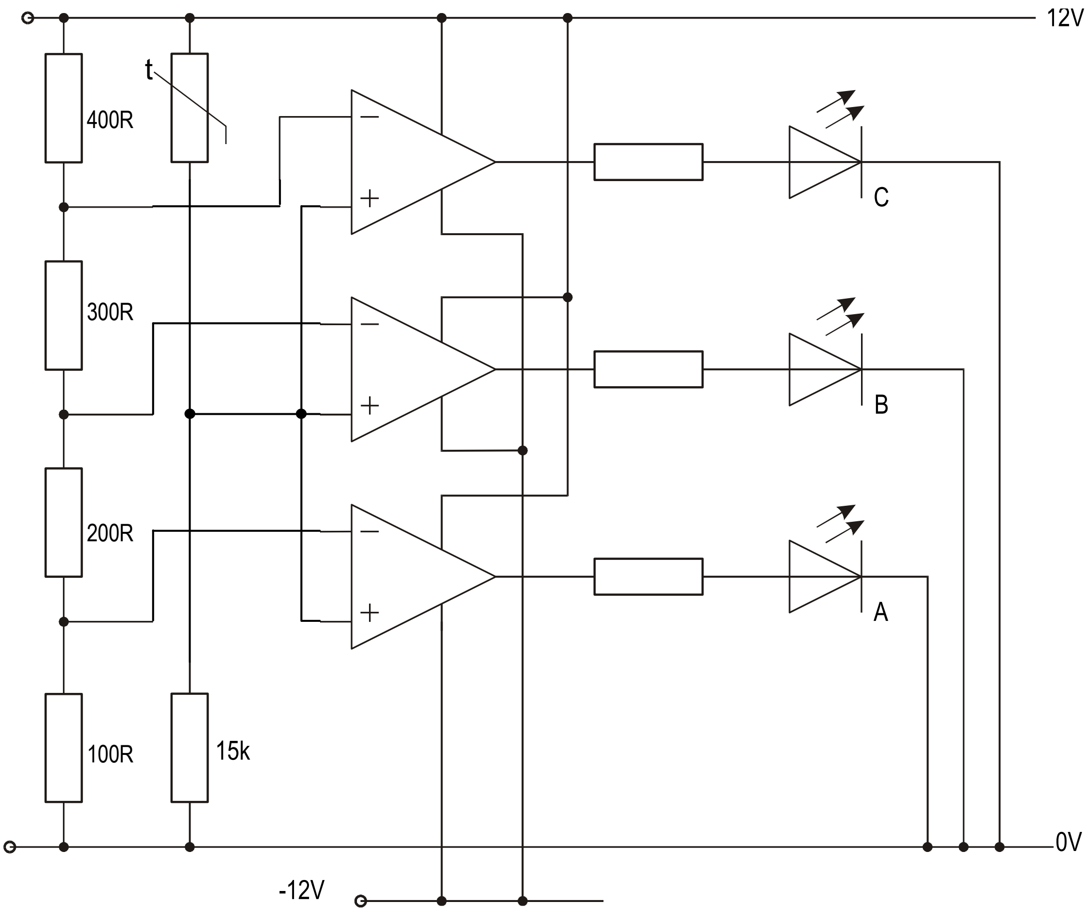
- (i) Name an additional device which can be added to the circuit to produce a positive value for V_o.
- (ii) Draw the circuit for this additional device and indicate the value of any components used.

ASSIGNMENT 2.11

A deep-fat fryer incorporates a cooking oil temperature indicator. An array of LEDs is shown on the control panel and, as the temperature of the cooking oil increases, the LEDs light in a ladder sequence.



The circuit shown is used to control the lighting of the LEDs. The circuit utilises three 741 operational amplifier IC's and a type 6 thermistor.



(a) In which amplifier mode are the 741 Ics being used ?

(b) Explain in detail why the LEDs light up in sequence as the temperature of the oil increases. The function of the components in the circuit should be included in your explanation.

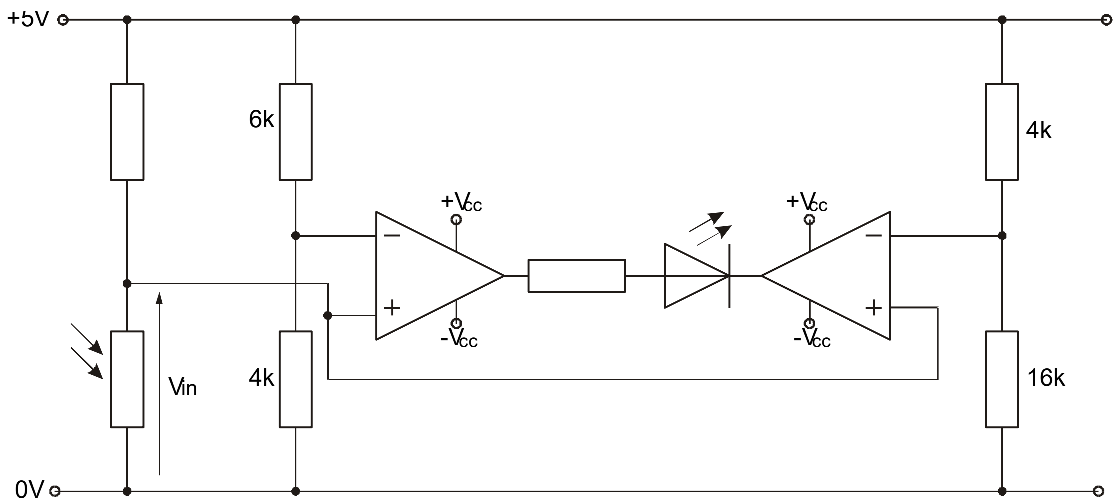
(c) At what temperature will LED "C" light ?

(d) If the current through each LED is to be limited to 200 mA, determine what value of resistor should be connected in series with each LED.

ASSIGNMENT 2.12

A camera manufacturer is evaluating a design for a light level indicator, details of which are shown in the circuit below.

Determine the **range** of values of the input voltage V_{in} over which the LED will glow to indicate that a photograph may be taken.



Homework – 2.1

Operational Amplifiers (Op. Amps) were originally made from discrete components and were designed to solve mathematical equations electronically by performing operations such as addition, etc. in analogue computers. Present day op. amps in integrated circuit form have many uses. One of the main ones being as high gain voltage amplifiers.

(a) Describe the chief properties of practical op. amps refering to;
 (i) open loop gain
 (ii) input impedance
 (iii) output impedance.

(b) Describe these properties as displayed by an 'IDEAL' op. amp.

(c) Sketch the basic diagram for an op. amp. which is supplied from a dual balanced d.c. power supply showing inputs and outputs.

(d) Describe its operation as a **difference amplifier**.

(e) Sketch a typical voltage characteristic graph on the axis shown in *fig. 2.1.1* below and describe the behaviour of the device over a range of inputs using the terms *saturation, linear range, difference input*.

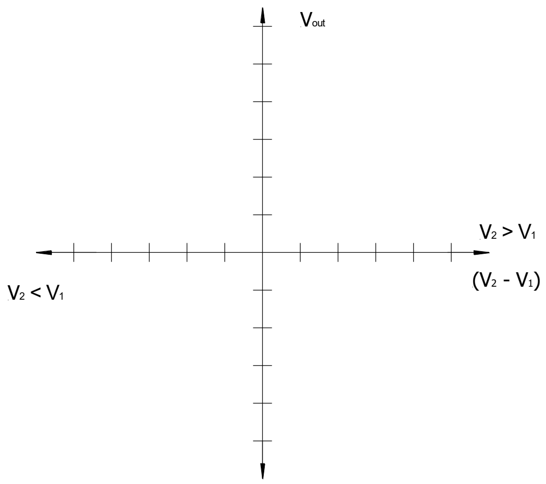


Figure 2.1.1

Homework – 2.2

(a) An inverting amplifier has a power supply of ±9V and the input voltage V_i = +1V. What is the value of the gain and the output voltage V_o when,
 (i) R_f = 20k and R_i = 10k
 (ii) R_f = 200k and R_i = 10k
 (iii) Sketch the circuit for the above examples.

(b) Repeat the above question when the op. amp is arranged as a non-inverting amplifier.

Homework – 2.3

An op. amp summing amplifier has 2 inputs. The power supply is ± 15V, and R_f = 30k the input resistors R_i each being 15k.

(a) Make a diagramatic sketch of circuit diagram for this arrangement.

(b) Calculate the output voltage V_o when
 (i) V_1 = +1V and V_2 = +4V
 (ii) V_1 = +1V and V_2 = -4V

Homework – 2.4
Op. amps are sometimes used in voltage-follower mode.

(a) Sketch this arrangement clearly labelling the diagram.
(b) Describe briefly how it operates.
(c) State a possible use for this configuration.

Homework – 2.5
The *figure 2.5.1* below represents a practical op. amp configuration.

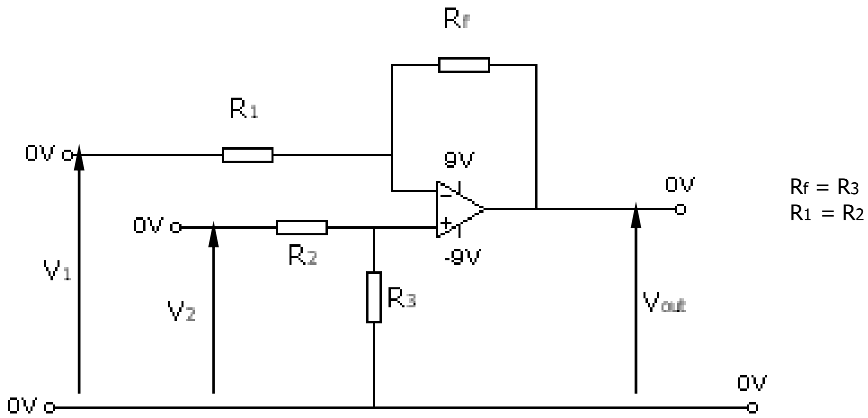


Figure 2.5.1

(a) Name this configuration and describe its operation refering to the inputs and outputs and values of reistors.
(b) Calculate the output voltage in each of the following cases.
  (i) $R_f = R_i$ = 1M ; V_1 = 2.4V ; V_2 = -4V
  (ii) R_f = 1M ; R_i = 100k ; V_1 = 4.5V ; V_2 = 3.5V

Homework – 2.6
An op. amp circuit is shown in the *figure 2.6.1* below.

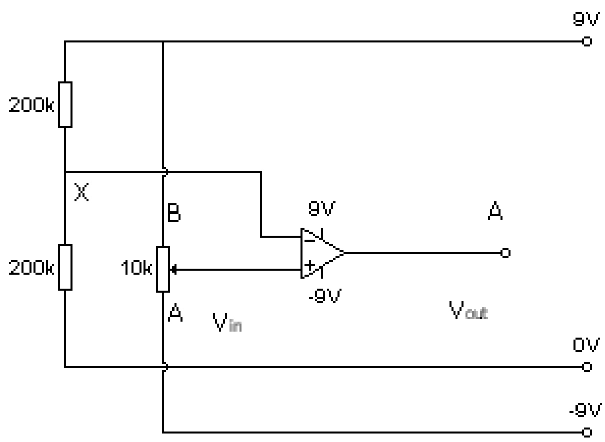
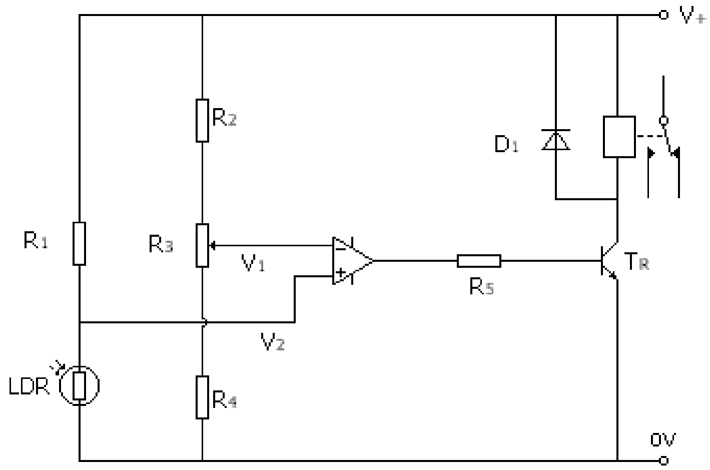


Figure 2.6.1

(a) Name this configuration
(b) State the voltage at point 'x'
(c) Sketch a graph of V_{in} (horizontal) against V_{out} (vertical) to show the relationship of V_{in} and V_{out} as the slider on the variable resistor moves from A to B.

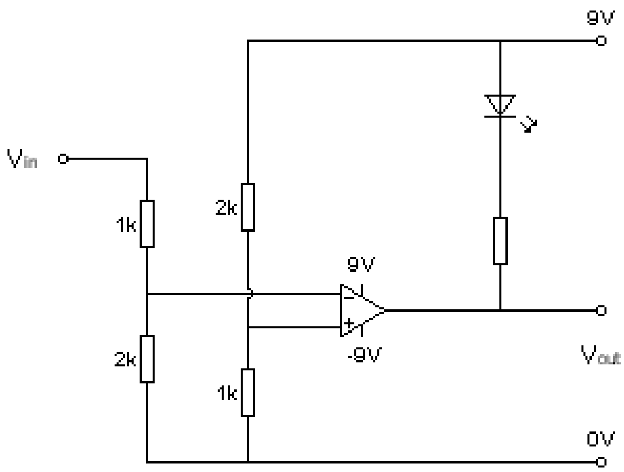
(d) The output is to be used to operate a darlington pair buffer amplifier which will drive a relay. Sketch a suitable arrangement for this circuit.
(e) Replace the darlington pair with a MOSFET buffer and sketch this arrangement.
(f) State two advantages of MOSFET's over bi-polar transistors.

Homework – 2.7
The circuit below shows a light activated switch which operates a relay.



(a) State the op. amp configuration used in this circuit.
(b) If the op. amp output is to be negative in normal daylight describe how the voltage levels V_1 and V_2 compare to give this.
(c) Describe what happens in darkness to ;
 (i) the LDR
 (ii) the relative values of V_1 and V_2.
 (iii) the output from the op. amp
 (iv) the transistor T_r
 (v) the relay
(d) State the function of the diode D1 in the circuit
(e) Show the modified circuit which will reverse the operation of the relay.

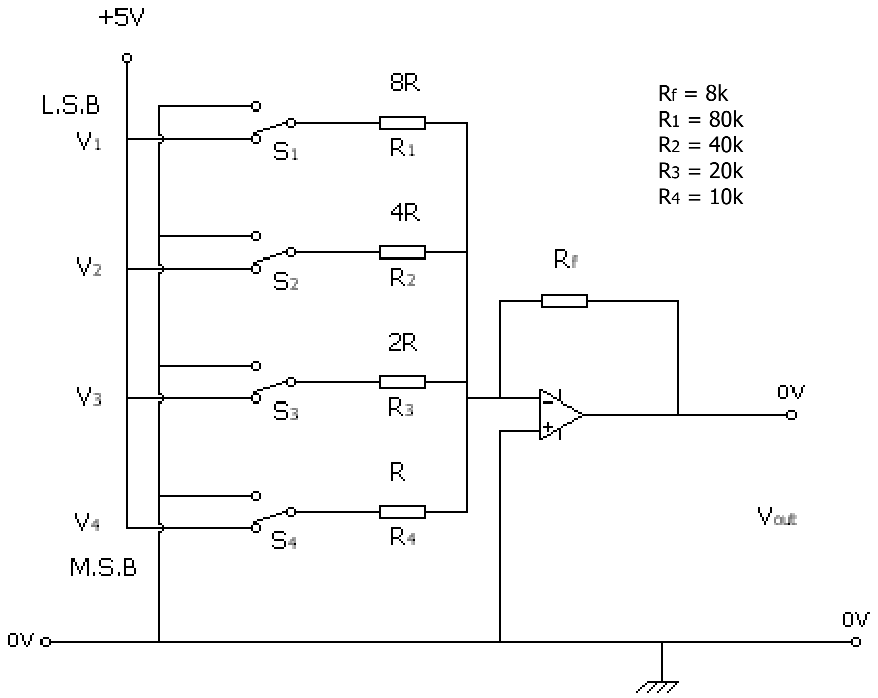
Homework – 2.8
(a) Calculate the voltage at the non-inverting input of the op. amp shown.
(b) Calculate the output voltage when V_{in} = 0.
(c) Describe the operation of the LED as V_{in} varies from 0 to 9V.



Homework – 2.9

The figure below shows a diagramatic sketch of a simple digital to analogue converter. The output V_{out} is governed by the position of the switches S_1 to S_4 which may be set high 1 (5V) or low 0 (0V).

The relative value of resistors $R_1 - R_4$ are chosen such that each is twice the value of the previous i.e: 8R, 4R, 2R, R. *(MSB – Most Significant Bit, LSB – Least Significant Bit)*



(a) Write down the equation for the output of a summing amplifier having 4 inputs and show that;

$$V_{out} = -(0.1V_1 + 0.2V_2 + 0.4V_3 + 0.8V_4)$$ *Volts for the values of R_1, R_2, R_3 & R_4 and R_f given.*

(b) Calculate the output voltage for the switch positions shown ie. All inputs high and also for all inputs low when R = 10k and R_f = 8k.

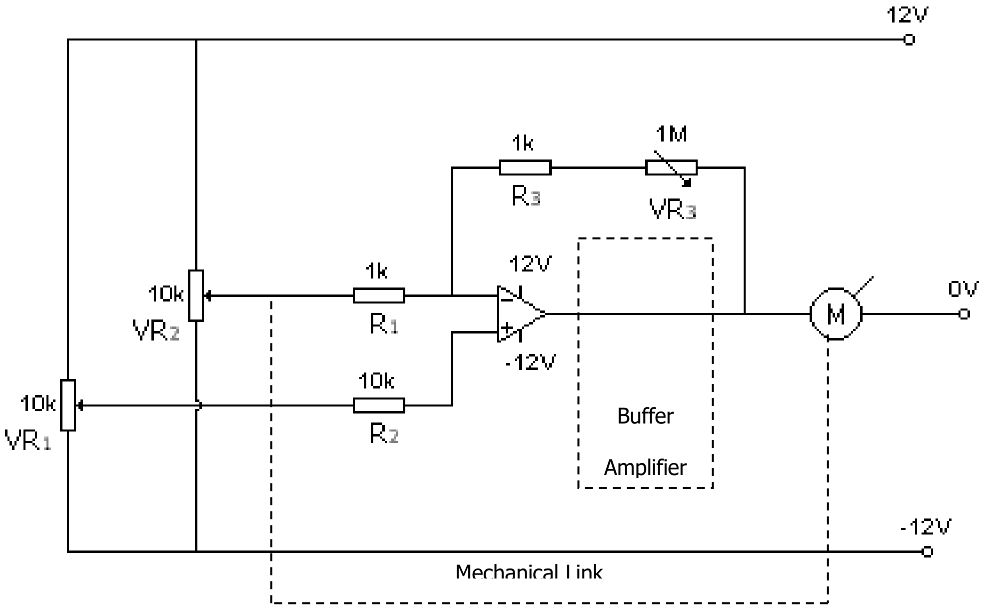
(c) Complete the table below by computing the output for all possible combinations of the 4 switches where V_1, V_2, V_3 & V_4 can be either 0V or 5V.

S_4	S_3	S_2	S_1	V_{out}
0	0	0	0	
0	0	0	1	
0	0	1	0	
0	0	1	1	
0	1	0	0	
0	1	0	1	
0	1	1	0	
0	1	1	1	
1	0	0	0	
1	0	0	1	
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	

(d) Show how the above system may be modified by adding an additional op. amp device which will give a positive output equal to 2 x V_{out}.

Homework – 2.10

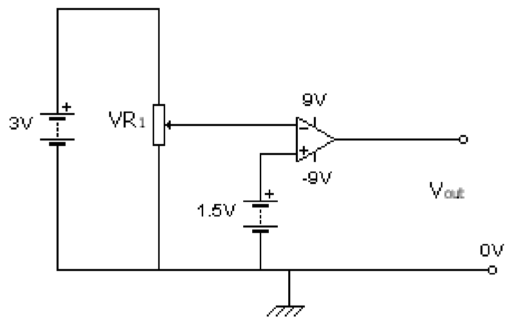
The system below is used to position an aerial remotely by adjusting V_{r1} to the required set position causing the aerial to move correspondingly.



(a) Sketch a suitable buffer amplifier which will meet the requirements of this system.
(b) Identify the amplifier configuration and describe how this system operates.

Homework – 2.11

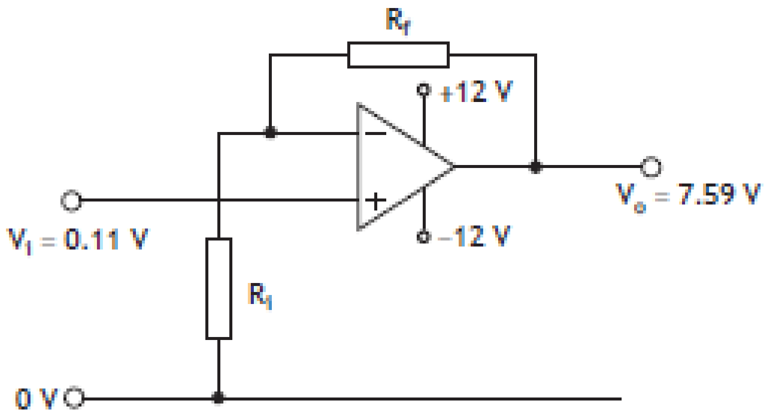
An op. Amp is connected as shown below.



(a) Name the op. Amp configuration.
(b) Explain what happens to V_o as R_1 is adjusted from 0 - R_1.
(c) Show on a sketched graph how the value of V_{out} varies as R_1 is adjusted.

2023 Past Paper

2. A design for an operational amplifier (op-amp) circuit is shown below.



(a) Calculate the gain for this circuit when the input voltage is 0.11 V. **1**

(b) Determine appropriate resistor values for R_i and R_f. **2**

6. An engineer designs a control system for hair straighteners to maintain a steady temperature. A comparator or a difference amplifier could be used in this application.

Describe the operation of these amplifiers in controlling temperature.

You must refer to both amplifiers in your answer. 3

Difference amplifier ____________________

____

____

____

Comparator ____________________

____

____

____

Difference amplifier or comparator ____________________

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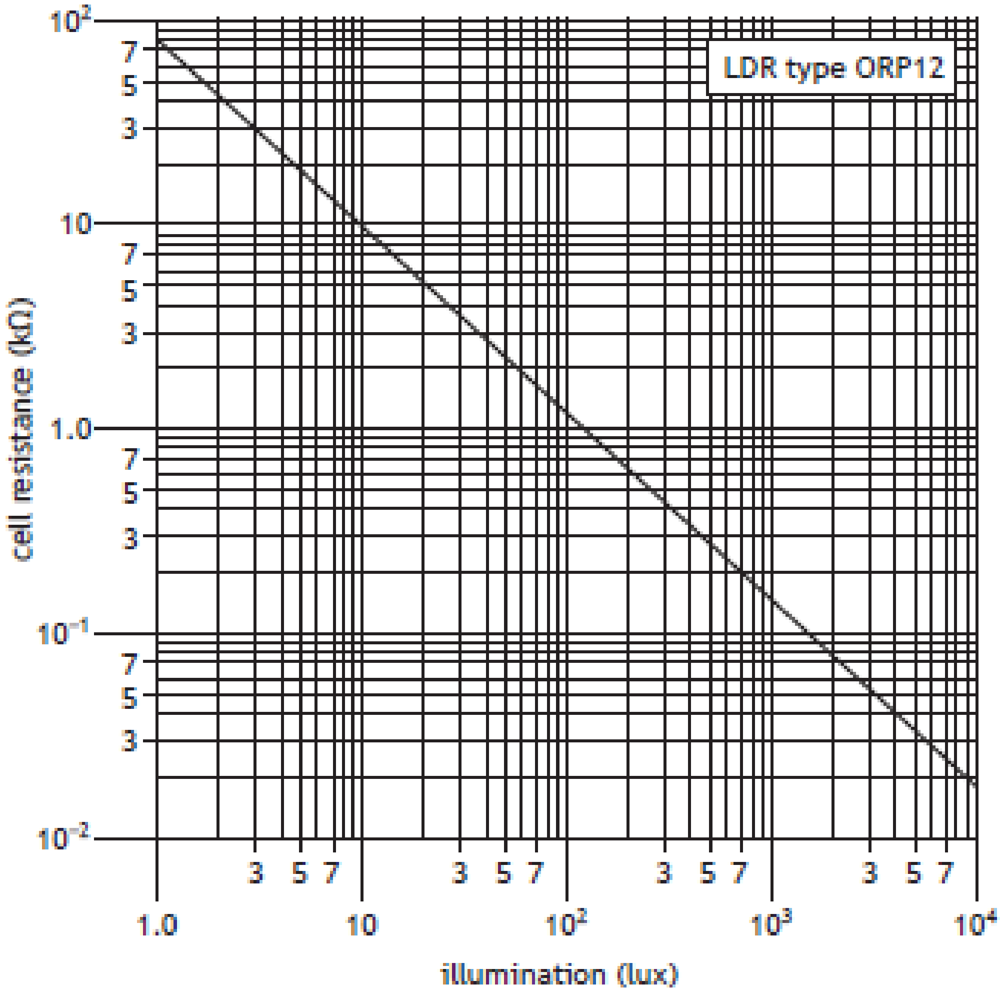
____

____

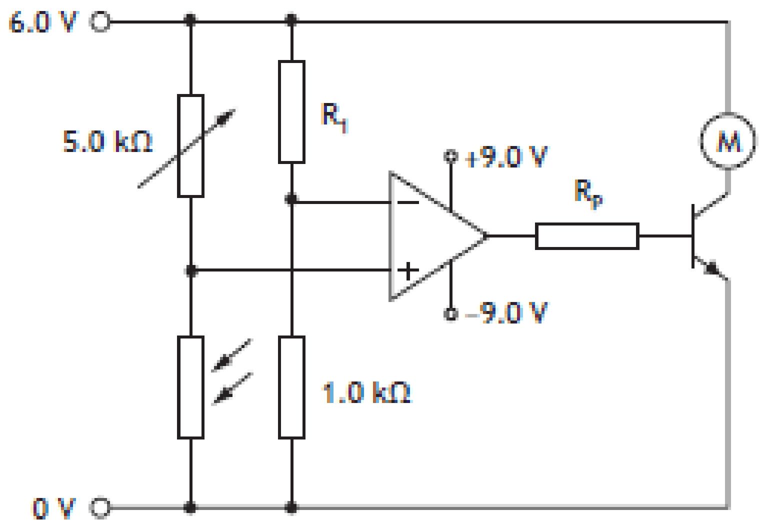
9. (continued)

Light Dependent Resistor (LDR) graph for an ORP12 LDR



A light sensor is used to identify when the plastic is dirty. When it senses a value of less than 210 lux a motor spins to move clean plastic in front of the camera.

The control circuit is shown below.



9. (continued)

(a) Calculate the value of R_1 required to saturate the op-amp positive at 210 lux. **3**

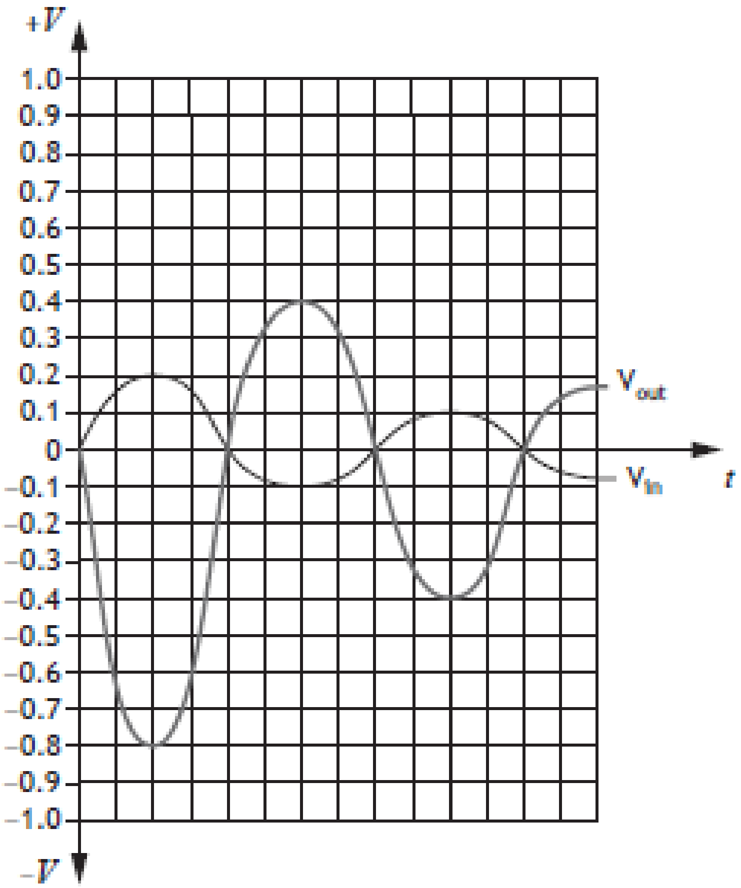
The motor requires 55 mA of current to operate.

The op-amp saturates to 78% of the supply voltage. V_{be} is 0.70 V when saturated. The transistor h_{fe} is 220.

(b) Calculate the required value of R_p. **4**

9. (continued)

An amplifier is required to boost the signal from the camera so that it can be transmitted. The graph below shows the desired output voltage for the given input.



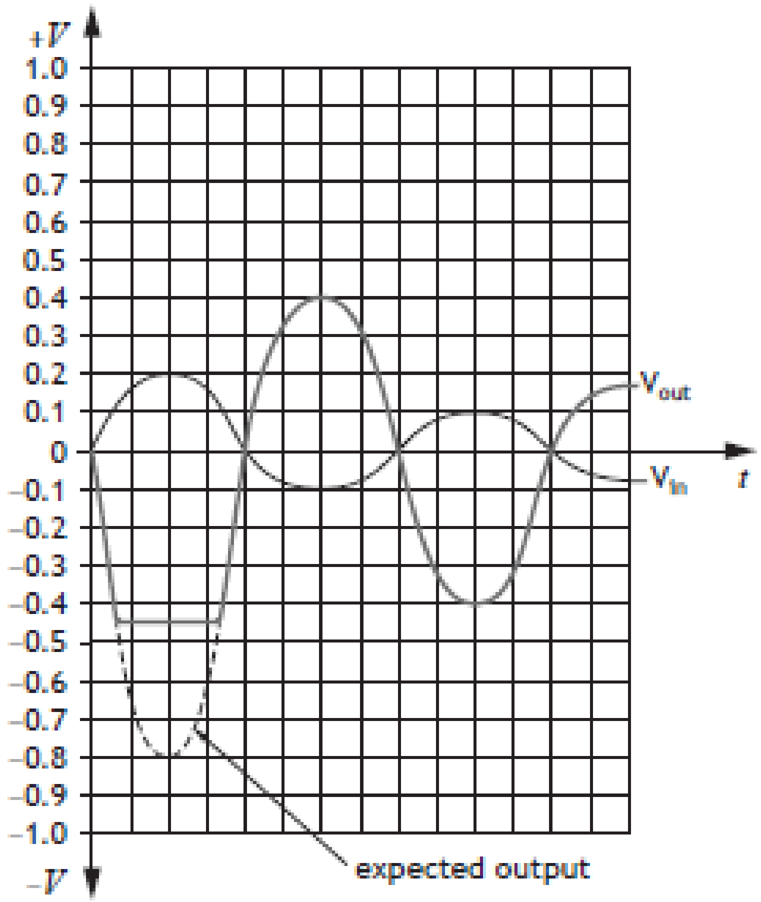
(e) State an op-amp configuration that will produce the desired output. **1**

____

(f) Calculate the required gain of the op-amp. **1**

9. (continued)

When testing the circuit, the output produced the following trace.

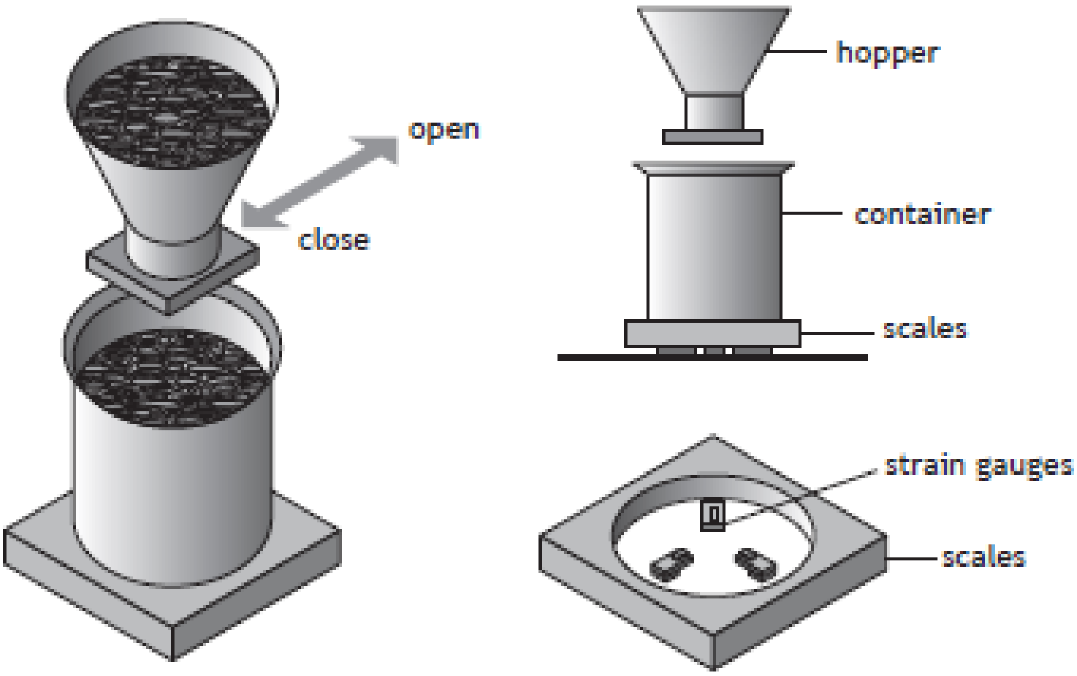


(g) State why the op-amp circuit produces the output shown. **1**

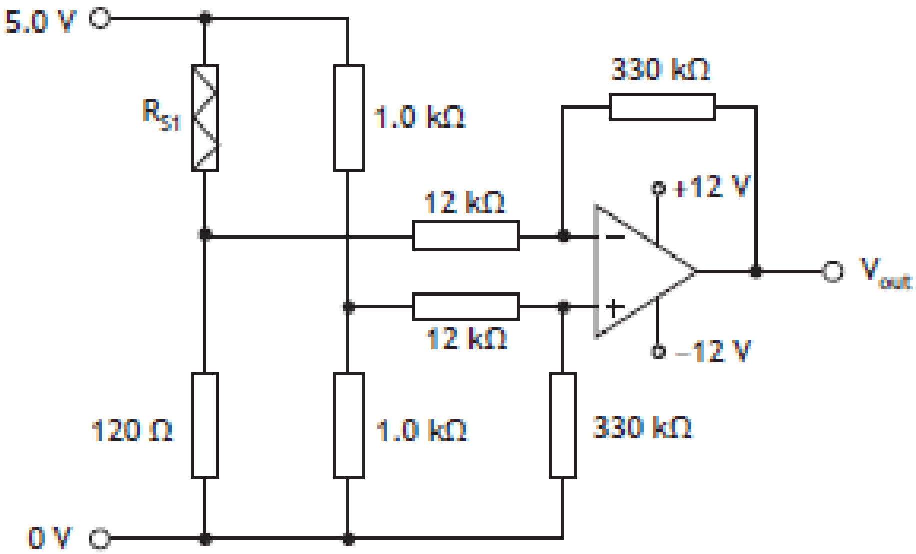
____

____

12. A science laboratory is investigating the use of an electronic control system to weigh chemical materials. The materials are released into a container from a hopper and are weighed using a scale comprised of three strain gauges.



A prototype circuit using a difference amplifier is produced to test one of the strain gauges as it weighs the materials.



12. (continued)

During an initial test R_{s1} was found to be 121.5 Ω.

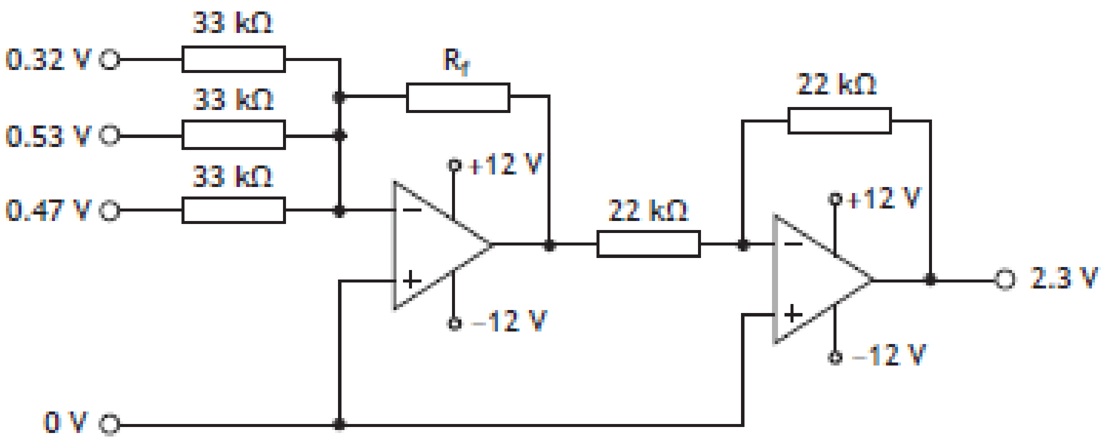
(a) Calculate V_{out}. **3**

12. (continued)

A difference amplifier circuit like the one shown in part (a) on *page 40* is used for each of the three strain gauges.

A further circuit is designed to combine their outputs. It must produce an output of 2.3 V when the correct amount of materials are added to the container.

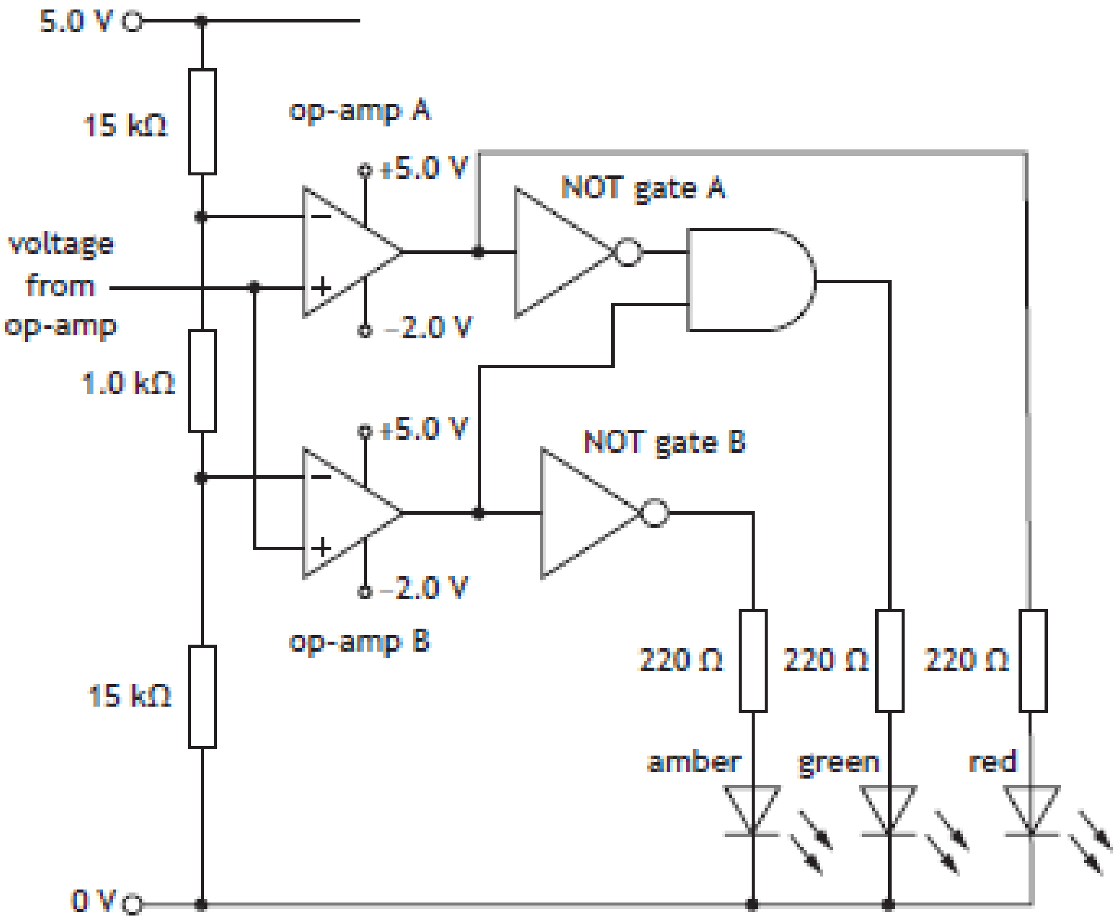
When the materials are added, the input and output voltages produced are shown below.



(b) Calculate a suitable value for R_f. **2**

12. (continued)

The output voltage is fed into a logic circuit to indicate whether an appropriate weight of materials is in the container.



An amber LED lights if there is not enough material. A green LED lights if there is the correct amount of material. A red LED lights if there is too much material. When the op-amps saturate negatively they will output 0 V.

12. (continued)

(c) Describe, with reference to the comparators, logic gates, and LEDs, what happens as the input signal rises from 0 V to 5.0 V. **3**